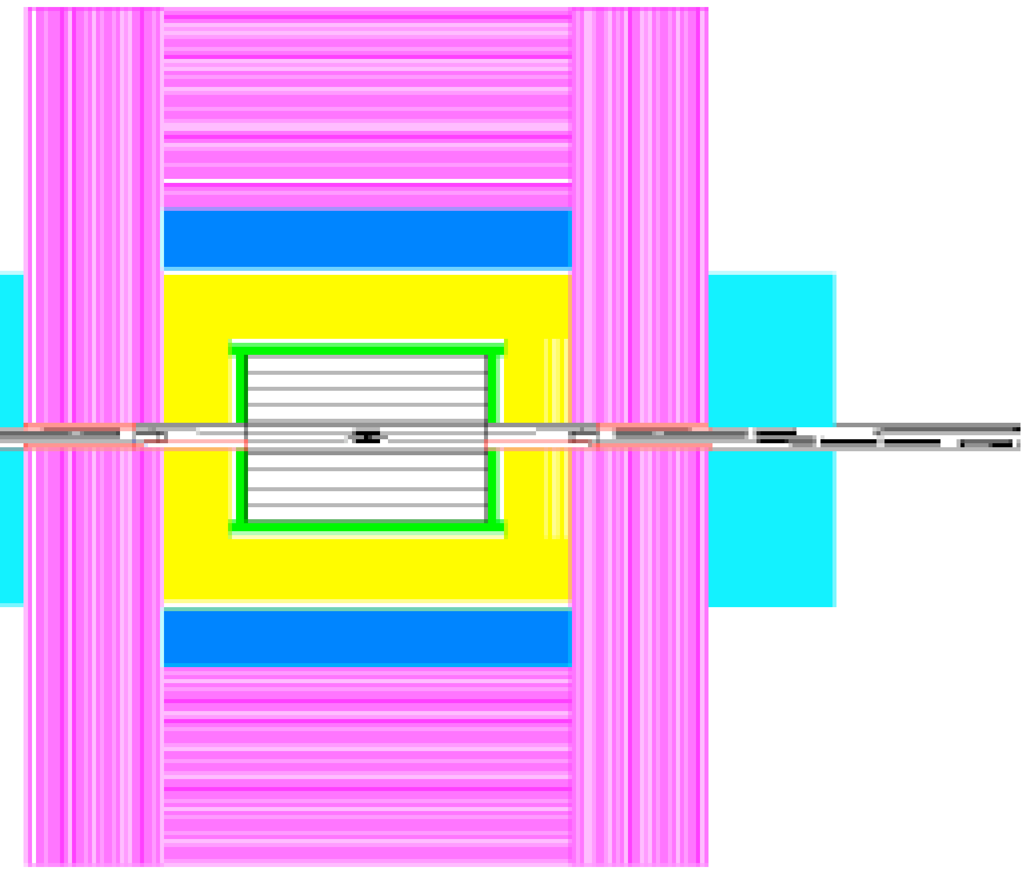
Where Machine and Detector Meet

Toward the ILC Community School
July 27th, 2007
FNAL

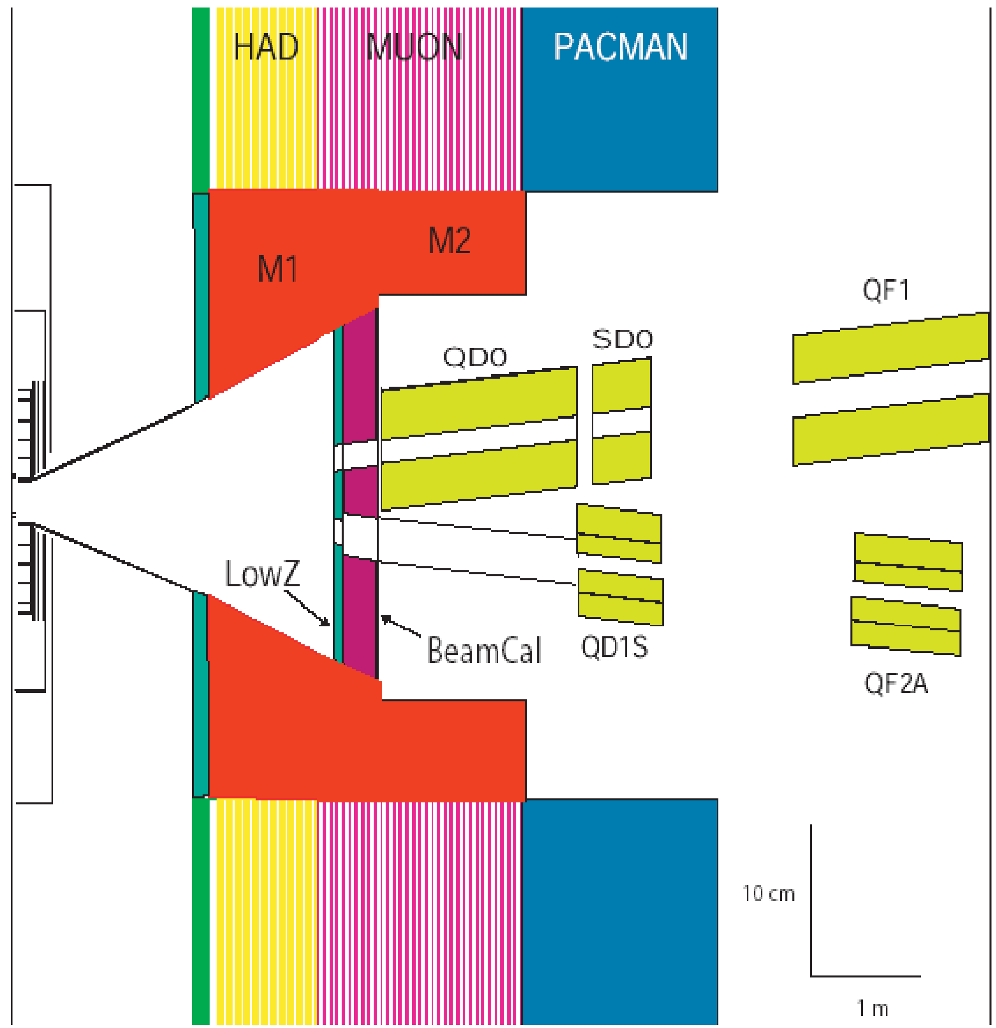
Eric Torrence
University of Oregon

Interaction Point

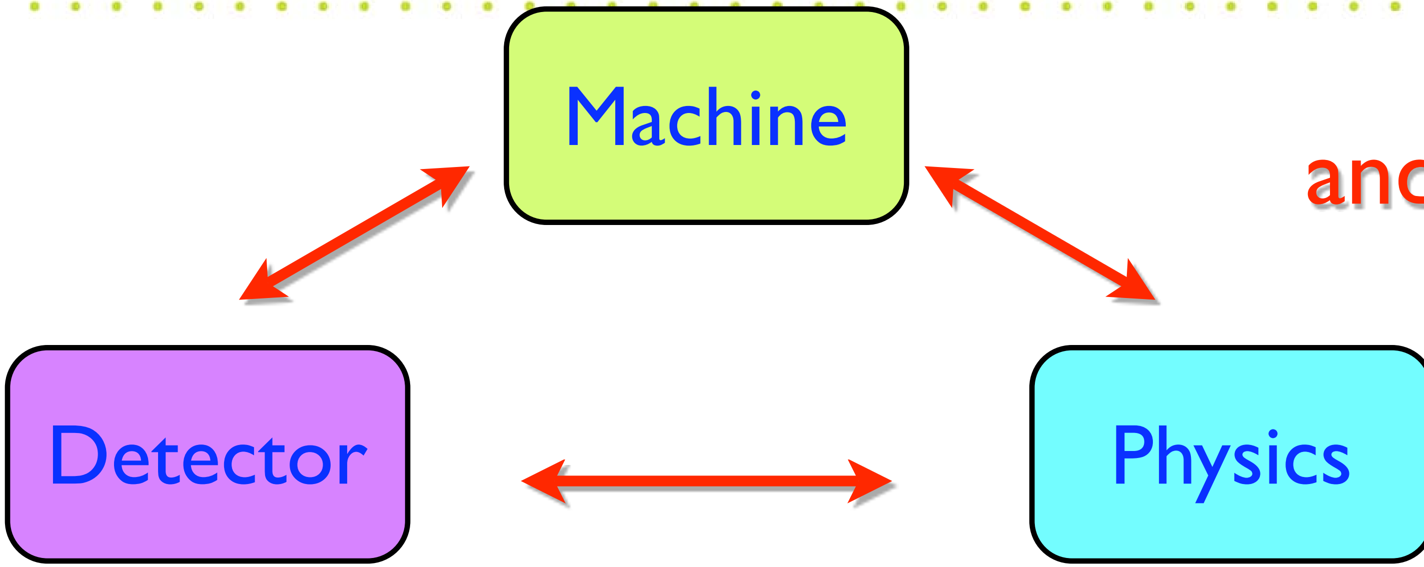
Detector View



Machine View



Machine-Detector Interface



and Cost!

Complicated optimization
ultimate goal is physics program

- High Luminosity
- Acceptable detector backgrounds
- Precise collision parameters (Lumi, Energy, Pol)

Outline

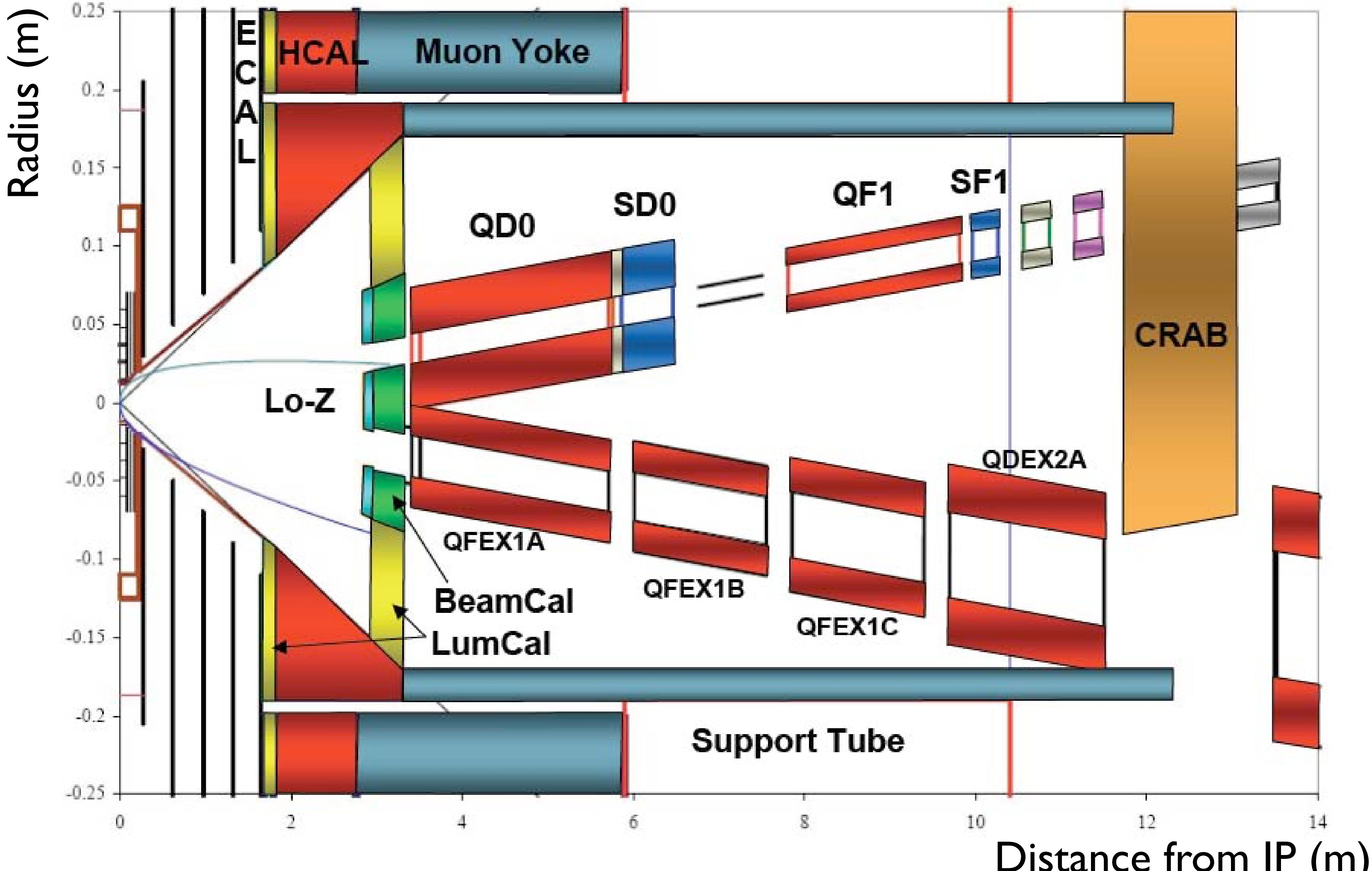
- Interaction Region - Beamstrahlung
- Detector Backgrounds
- Forward Calorimeters
- Beam Instrumentation
- IR Engineering

Complimentary to topics covered by A. Seyri

This talk is an overview of topics, not a review of the very latest results. I will particularly highlight areas where more effort would be most helpful.

Interaction Region Overview

IP Geometry



Radius (m)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
E
C
A
L
HCAL
Muon Yoke
QD0
SD0
QF1
SF1
CRAB
Lo-Z
QDEX2A
QFEX1A
QFEX1B
QFEX1C
BeamCal
LumCal
Support Tube
0
2
4
6
8
10
12
14
Distance from IP (m)

Collision Parameters

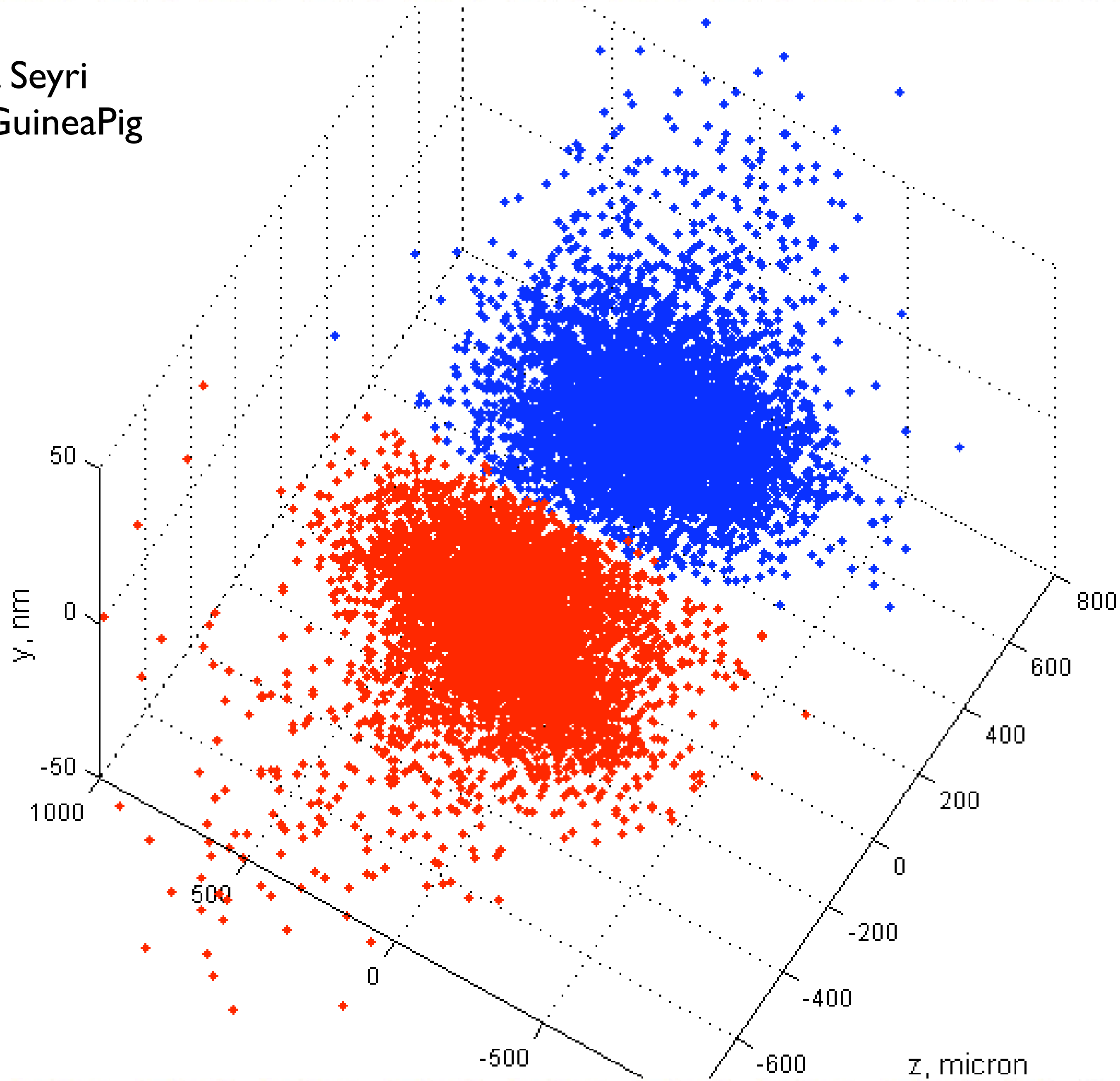
Parameter	Min	Typical	Max	
N_{bunch}	1	2	2	$\times 10^{10}$
σ_x	474	640	640	nm
σ_y	3.5	5.7	9.9	nm
σ_z	200	300	500	μm
D_y	14	19	26	

$$D_y = \frac{2Nr_e\sigma_z}{\gamma\sigma_y(\sigma_x+\sigma_y)}$$

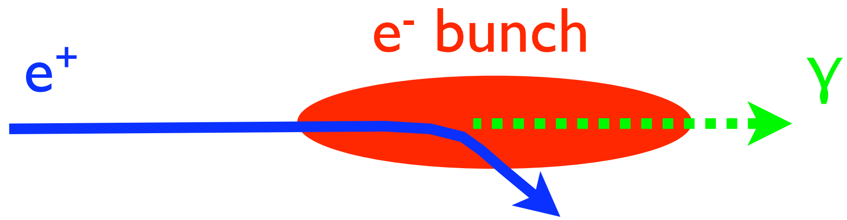
- Very strong fields in collision process
- Large vertical disruption factor
  - Beams self-focus - enhanced luminosity, z-correlations
  - Acceleration of particles - "beamstrahlung" radiation
  - Generally called "beam-beam" effects

Gratuitous Animation

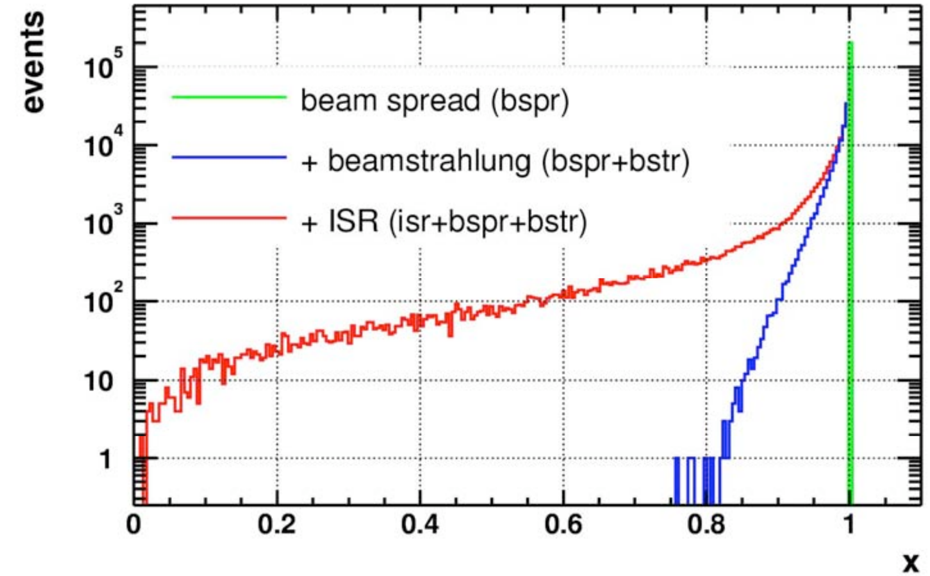
Animation: A. Seyri
Simulated with GuineaPig

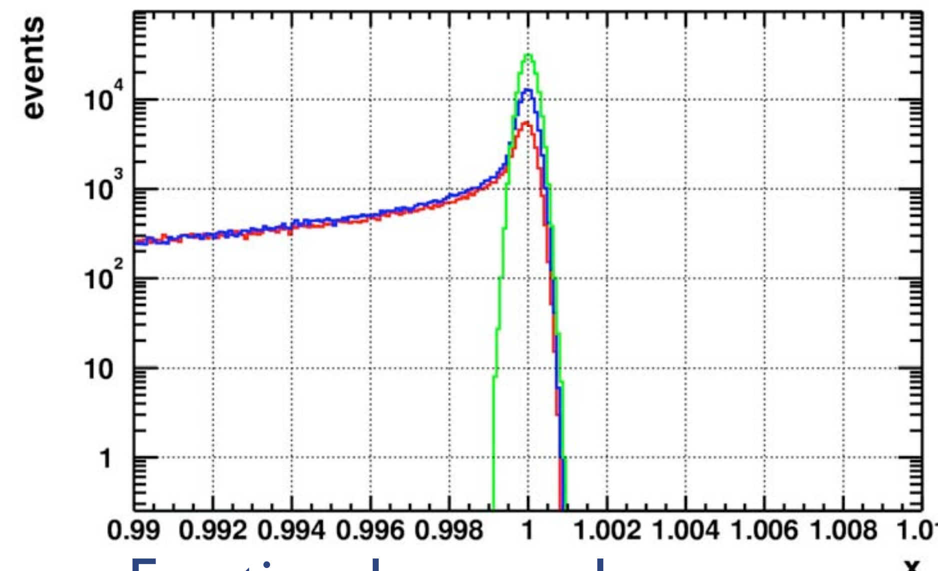


Beamstrahlung



- $\langle E_\gamma \rangle / E_{beam}$ from 2-5%
- Distorts luminosity spectrum
- Photons inside bunch produce secondary pairs
- Highly dependent on collision parameters (beam size, offsets, ...)





Fractional energy loss

Major new challenge at ILC for e^+e^- physics program

Parameter Sets

TABLE 2.1-2
Beam and IP Parameters for 500 GeV cms

Parameter	Symbol/Units	Nominal	Low N	Large Y	Low P
Repetition rate	f_{rep} (Hz)	5	5	5	5
Number of particles per bunch	N (10^{10})	2	1	2	2
Number of bunches per pulse	n_b	2625	5120	2625	1320
Bunch interval in the Main Linac	t_b (ns)	369.2	189.2	369.2	480.0
in units of RF buckets		480	246	480	624
Average current in the Main Linac	I_{ave} (mA)	9.0	9.0	9.0	6.8
Normalized emittance at IP	$\gamma\epsilon_x^*$ (mm·mrad)	10	10	10	10
Normalized emittance at IP	$\gamma\epsilon_y^*$ (mm·mrad)	0.04	0.03	0.08	0.036
Beta function at IP	β_x^* (mm)	20	11	11	11
Beta function at IP	β_y^* (mm)	0.4	0.2	0.6	0.2
R.m.s. beam size at IP	σ_x^* (nm)	639	474	474	474
R.m.s. beam size at IP	σ_y^* (nm)	5.7	3.5	9.9	3.8
R.m.s. bunch length	σ_z (μm)	300	200	500	200
Disruption parameter	D_x	0.17	0.11	0.52	0.21
Disruption parameter	D_y	19.4	14.6	24.9	26.1
Beamstrahlung parameter	Υ_{ave}	0.048	0.050	0.038	0.097
Energy loss by beamstrahlung	δ_{BS}	0.024	0.017	0.027	0.055
Number of beamstrahlung photons	n_γ	1.32	0.91	1.77	1.72
Luminosity enhancement factor	H_D	1.71	1.48	2.18	1.64
Geometric luminosity	$\mathcal{L}_{geo}$ $10^{34}/\text{cm}^2/\text{s}$	1.20	1.35	0.94	1.21
Luminosity	$\mathcal{L}$ $10^{34}/\text{cm}^2/\text{s}$	2	2	2	2

Detector Backgrounds

(the dirty work)

Background Sources

Interaction Point

Scale with lumi - good
shield from detectors

- BSL photons
- e^+e^- pairs
- backscattered γ or n from pairs
- Radiative Bhabhas
- Hadronic 2γ

Machine

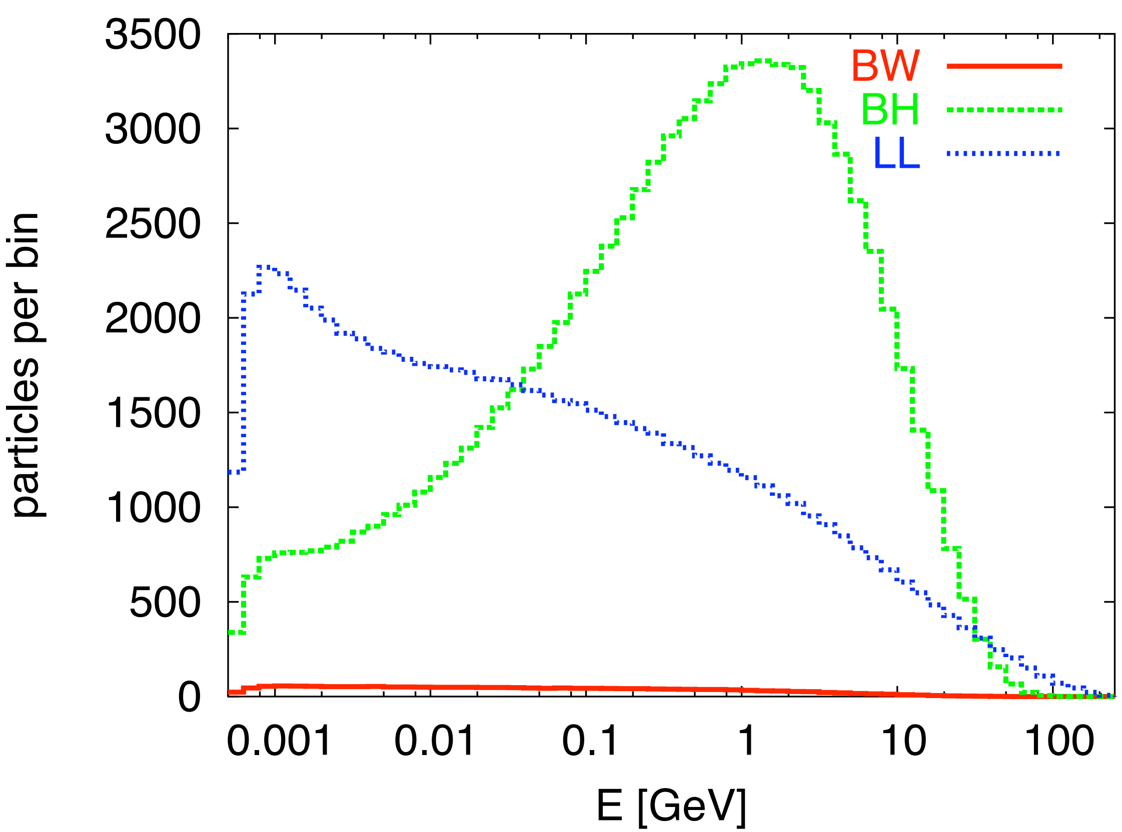
Independent of lumi - bad
avoid near IP

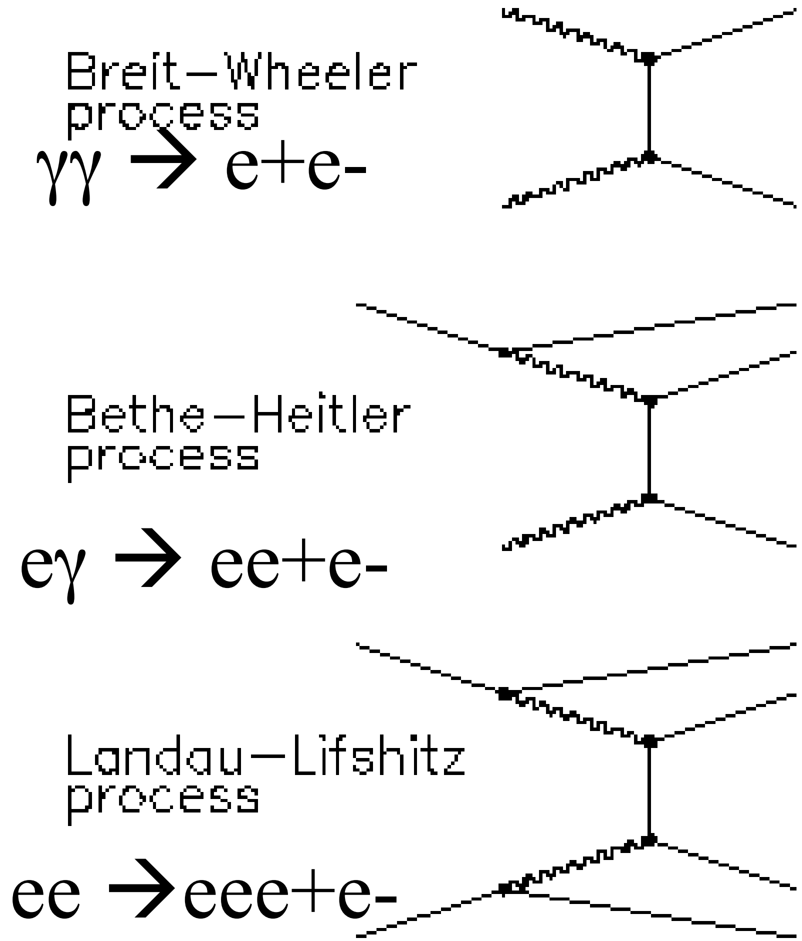
- Neutron back-shine from dump
- Synchrotron radiation
- Muon production
- Collimator scraping

Primarily worried about vertex detector and tracking volume.

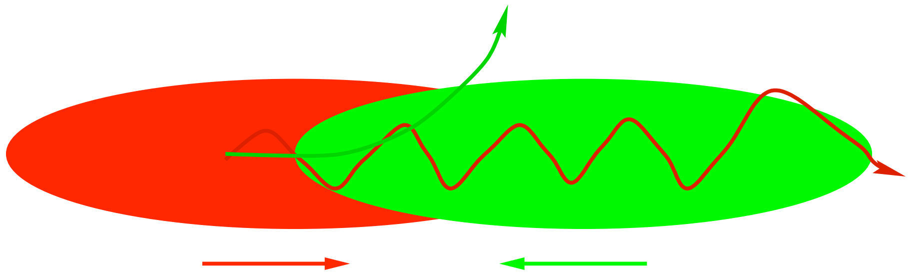
BSL Pair Production

- Bethe-Heitler generally most problematic
- Some uncertainty due to beam-size effects



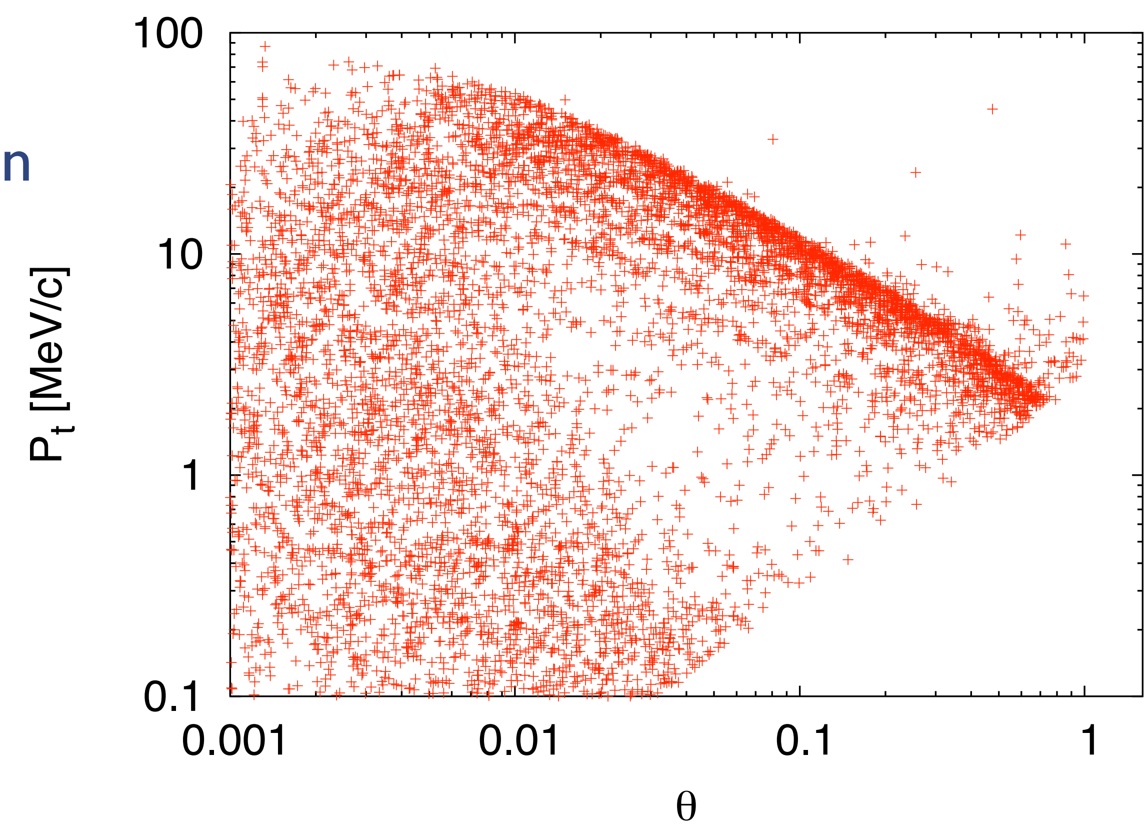


Deflection by Beams



- Pairs produced inside bunch
- Fields either focus them in, or kick them out

- Correlation between deflection angle and max Pt
- Bethe-Heitler "hard edge"
- Landau-Lifshitz outside

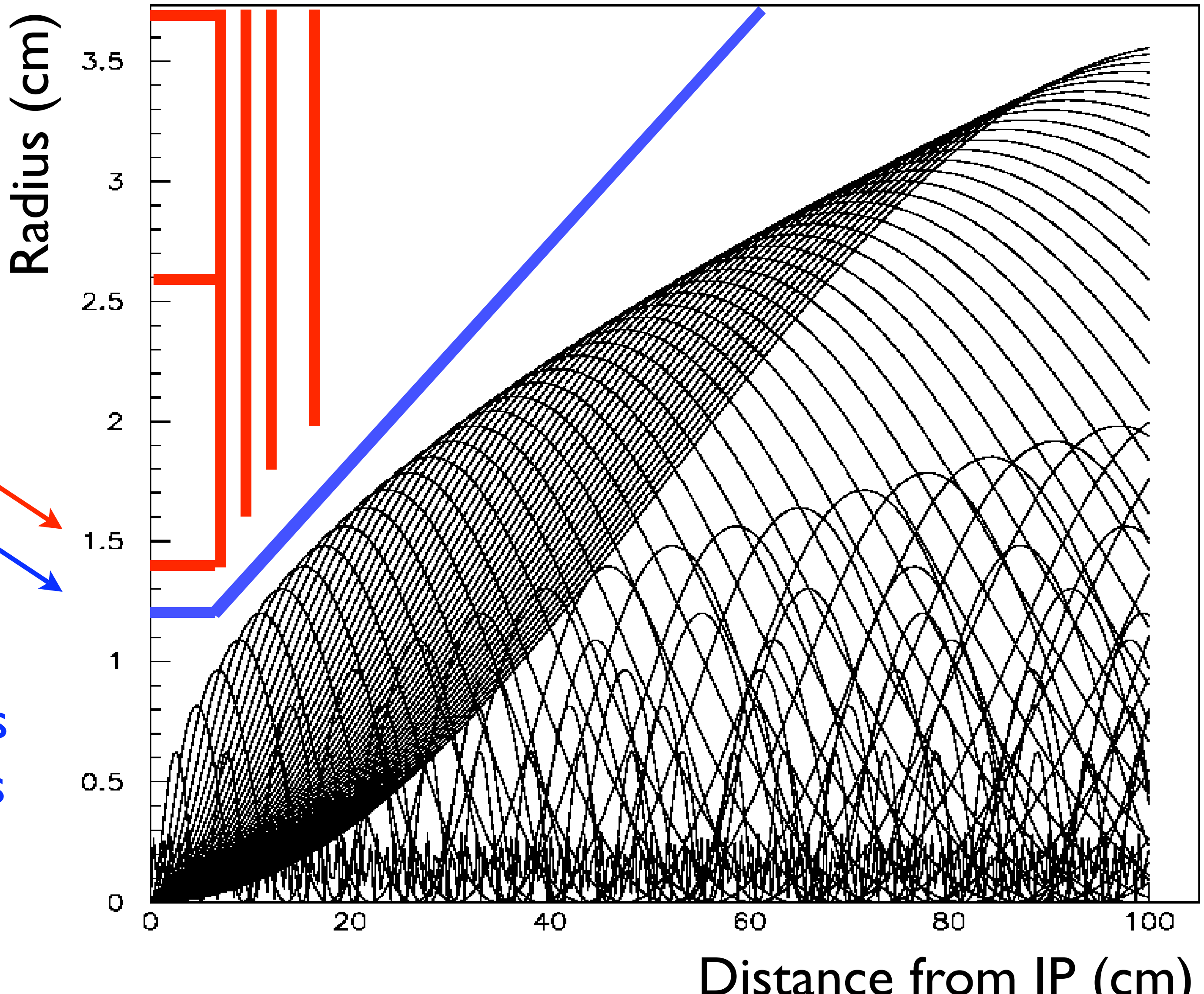


Pairs in detector

Simulation of B-H edge in 5T solenoid

Vertex Detector
(minimize R)

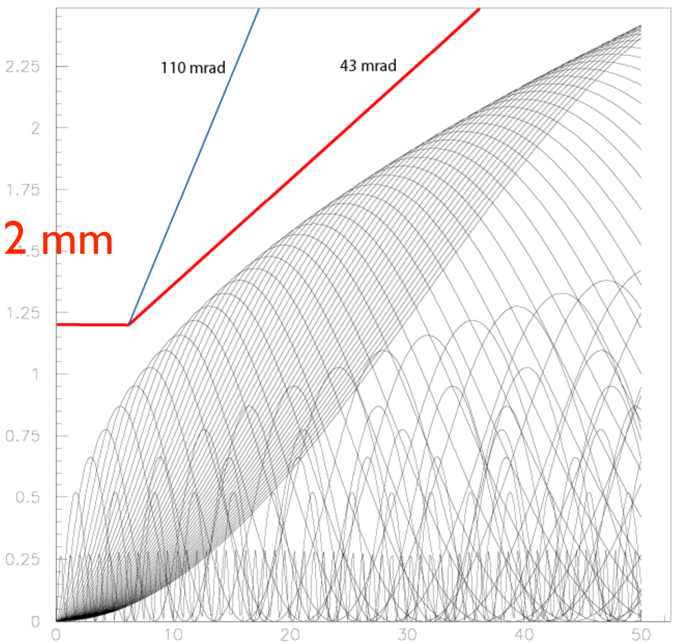
Beampipe



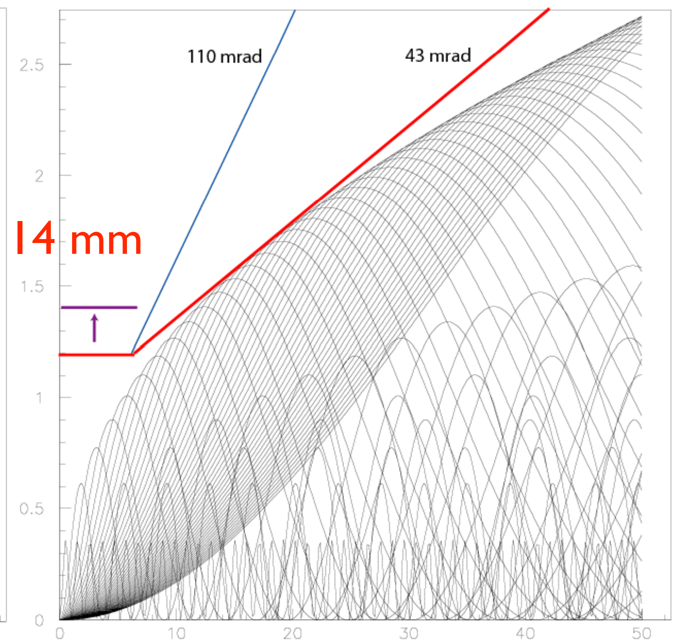
Avoid direct B-H hits
Remaining direct hits
combination of
B-H and L-L pairs

Vertex Tolerances

5 Tesla

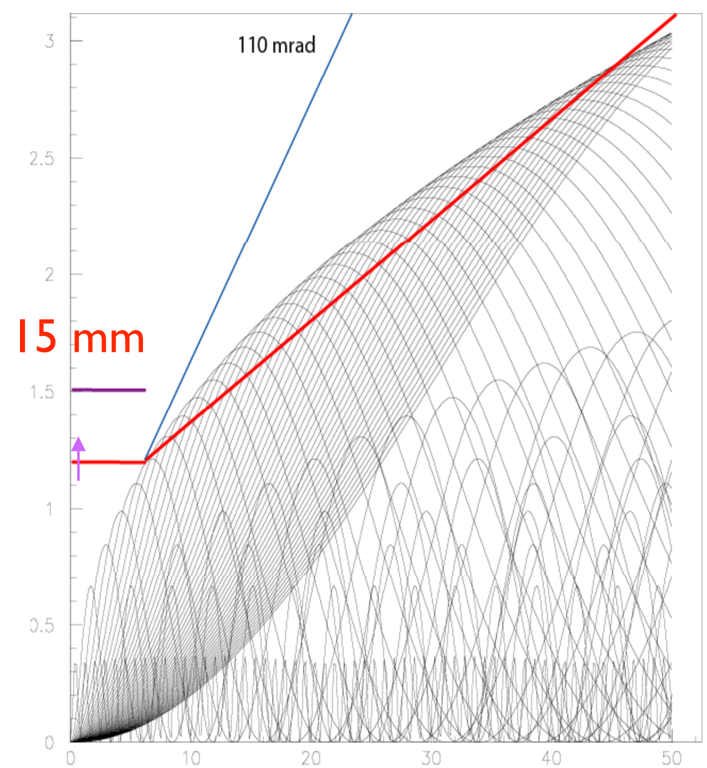


4 Tesla



T. Maruyama, LCWS07

500 GeV Low P + 5 Tesla

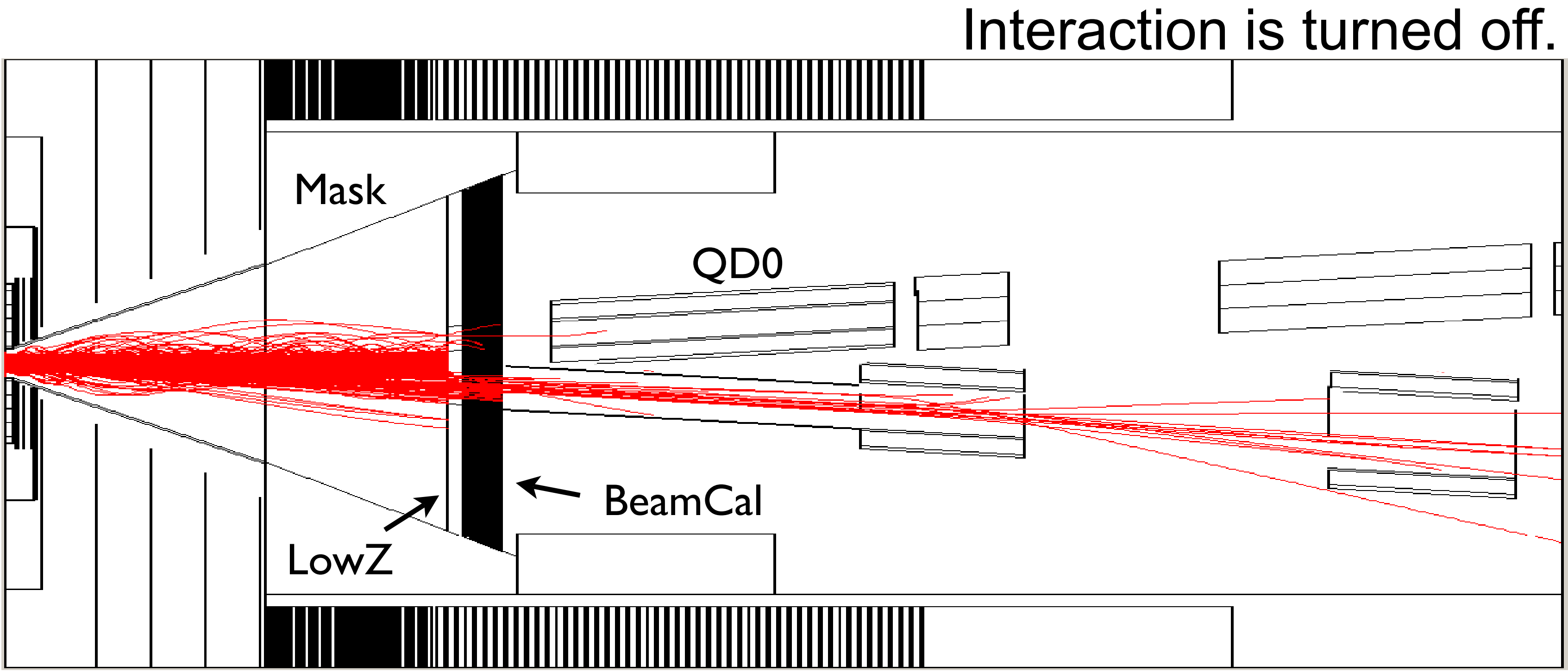


Depends on B-field and collision parameters

Need some safety factor, but how much?

Active area in detector design
More physics studies on R_{min} useful

Pair Backscatter



- Pairs hit BeamCal near QD0 face, backscatter γ or n
- Detector rates very dependent on specific geometry, B field

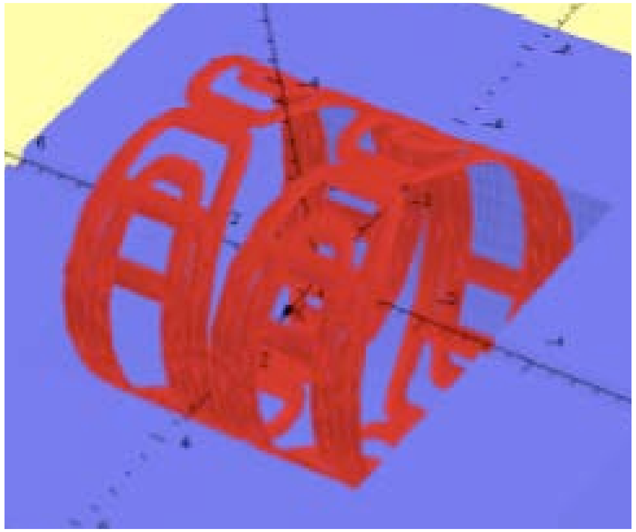
  ~10% of vertex hits, dominant part of tracking background

Era of generic background studies over.
Concept-specific studies with detailed IR geometry needed!

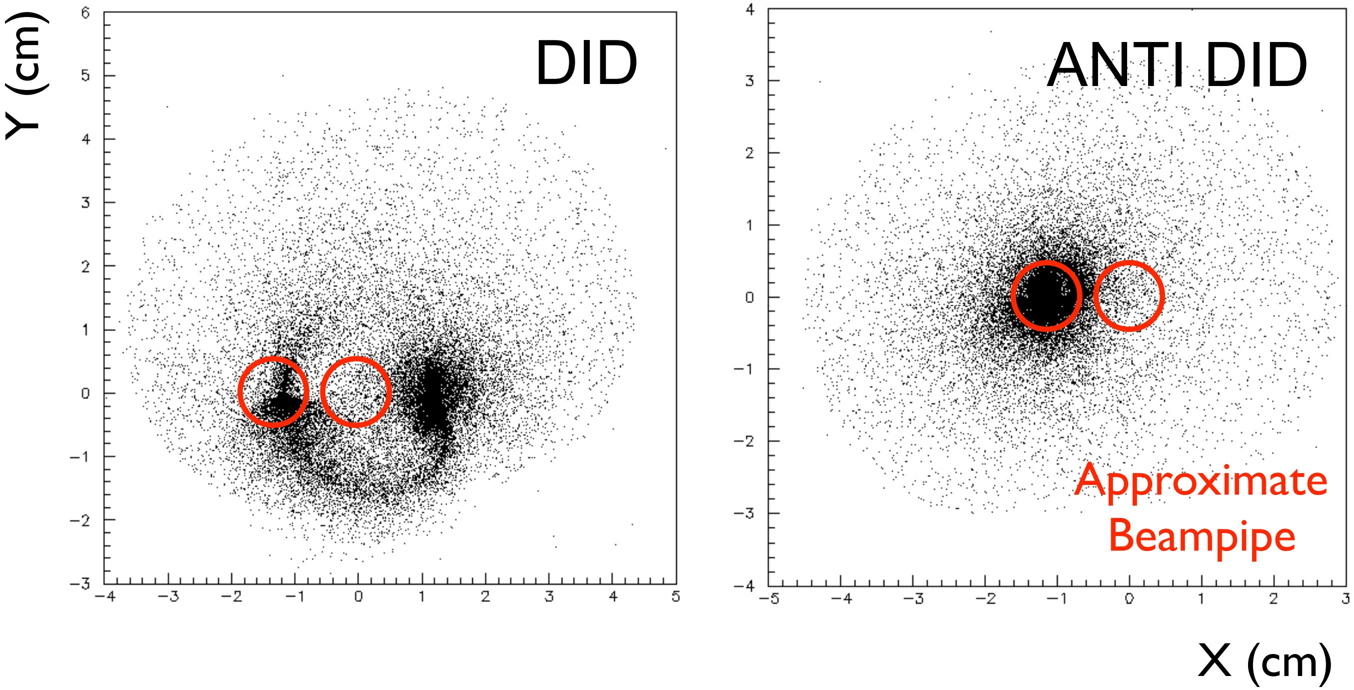
(anti-) DID

Detector Integrated Dipole

- Additional windings to "kink" solenoid field
- DID - aligned along incoming beam
- anti-DID - aligned along outgoing (pairs)



B. Parker



Anti-DID puts more pairs into outgoing beampipe, lower detector backgrounds

Need complete 3D B-field in background simulation

Example VXD backgrounds

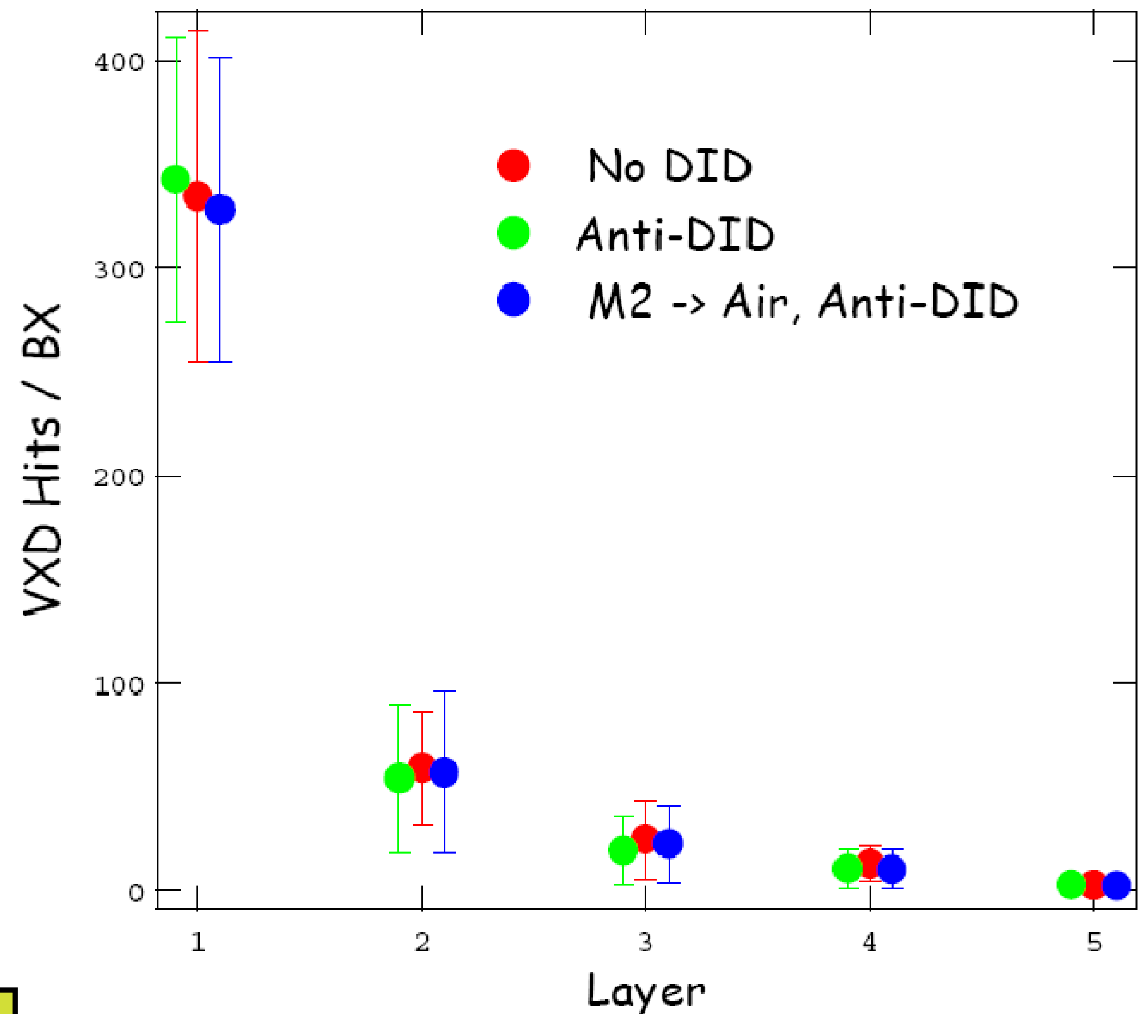
Is this OK? It depends...

Appears fine for damage (neutrons dominate this)

1% occupancy/readout window gives ~400 hits/BX (Witold criterion, Snowmass `05)

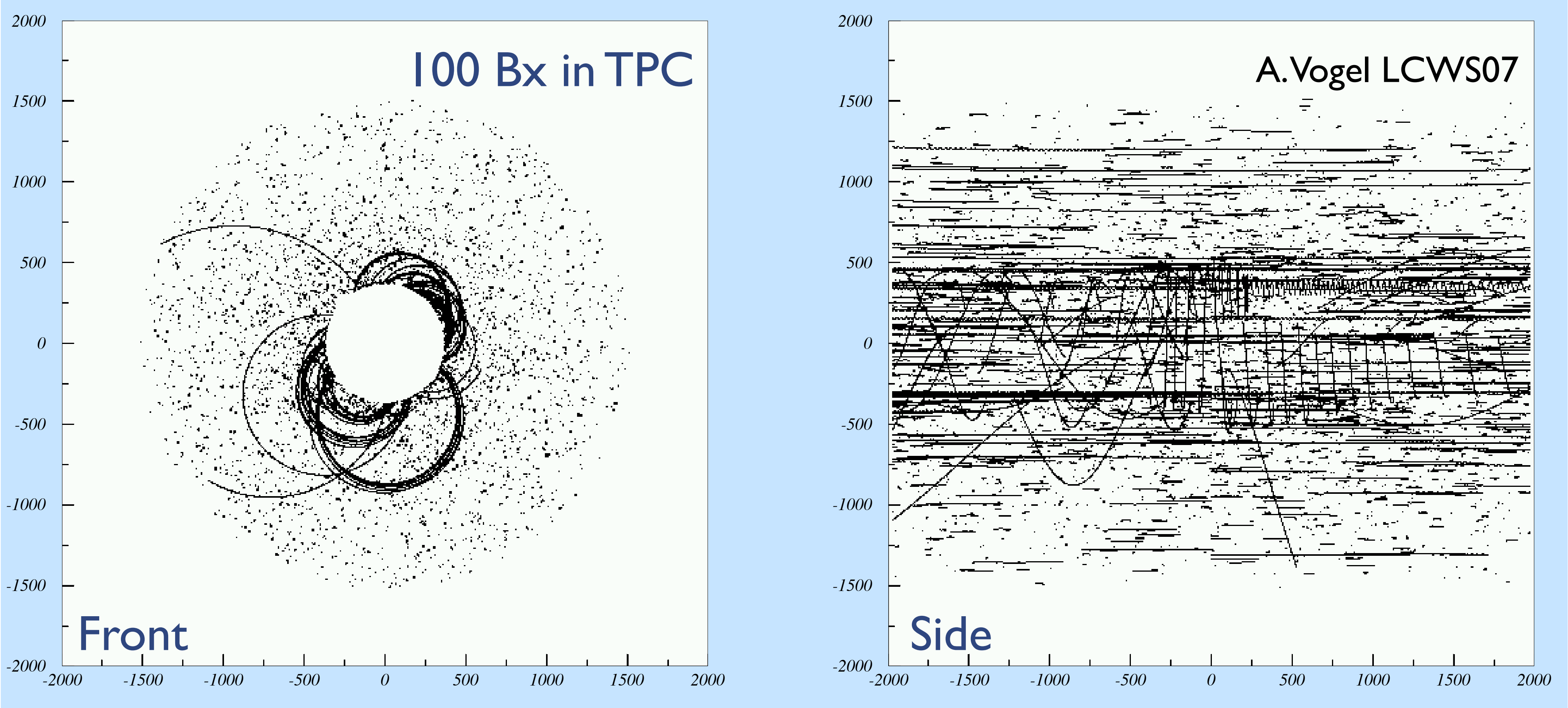
Conservative, but need x10 safety

Need more physics performance studies w/ full backgrounds



SiD Study
T. Markiewicz LCWS07

Tracker backgrounds

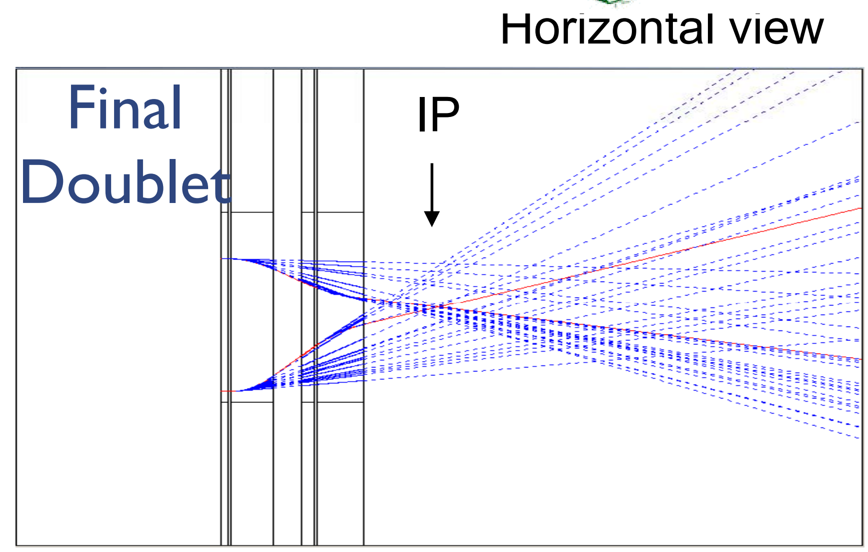


- Dominated by pair backscatter
- Diffuse hits less dangerous than correlated loopers
- Need detailed physics benchmarks to properly evaluate, figure-of-merit numbers generally misleading

Other important backgrounds

- Synchrotron radiation

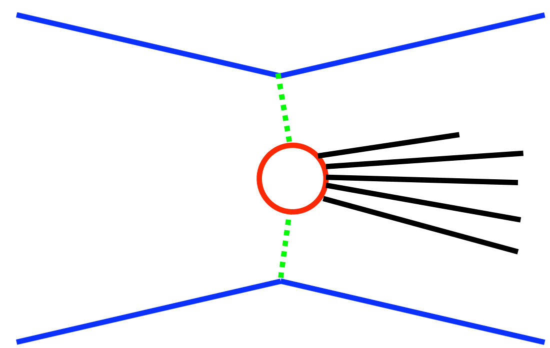
Potentially dangerous, particularly in early days when beam conditions aren't perfect
Need more studies with "bad" beams



- Hadronic 2-photon

Very high cross-section
Expect 10s GeV in forward region per readout window
Has not been looked at in a long time, muons too...

$e^+e^- \rightarrow e^+e^- + \text{jets}$



T. Barklow, 2004

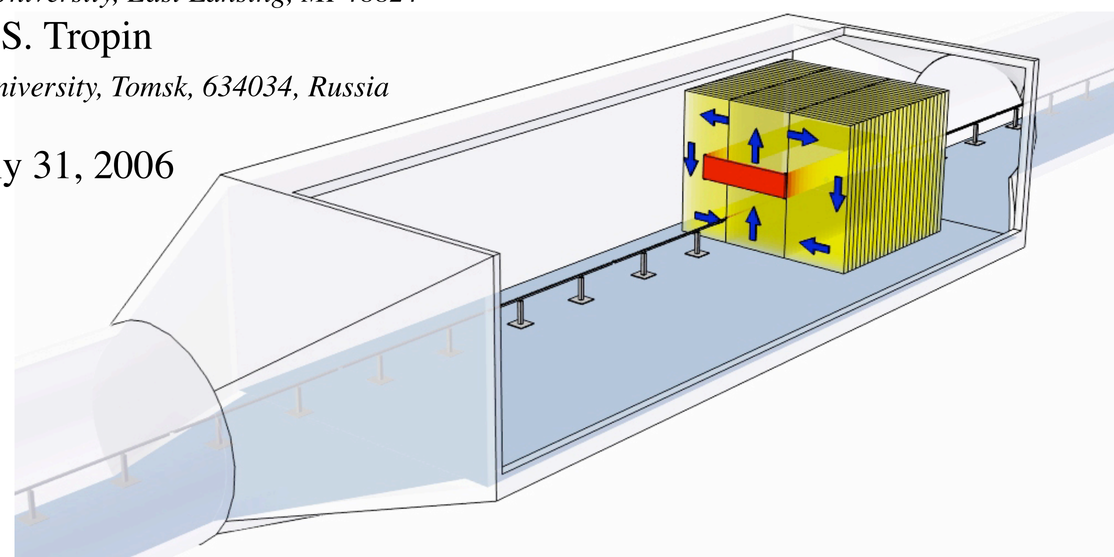
Machine Backgrounds in SiD

FERMILAB-FN-0790-AD July 2006

Machine-Related Backgrounds in the SiD Detector at ILC*

D.S. Denisov, N.V. Mokhov, S.I. Striganov
Fermilab, P.O. Box 500, Batavia, IL 60510
M.A. Kostin
NSCL, Michigan State University, East Lansing, MI 48824
I.S. Tropin
Tomsk Polytechnic University, Tomsk, 634034, Russia

July 31, 2006



STRUCT/MARS simulations
Foundation for design of muon shielding in beam delivery

Significant work/experience already at FNAL

Background Summary

- Beamstrahlung pairs most studied - beware "lampost"
- Simulation work mostly done by concept groups
- Need detailed IR geometry, field maps, and detector descriptions

> - More variation of machine parameters and operating conditions needed
> - Incorporate backgrounds directly into physics and performance benchmark studies

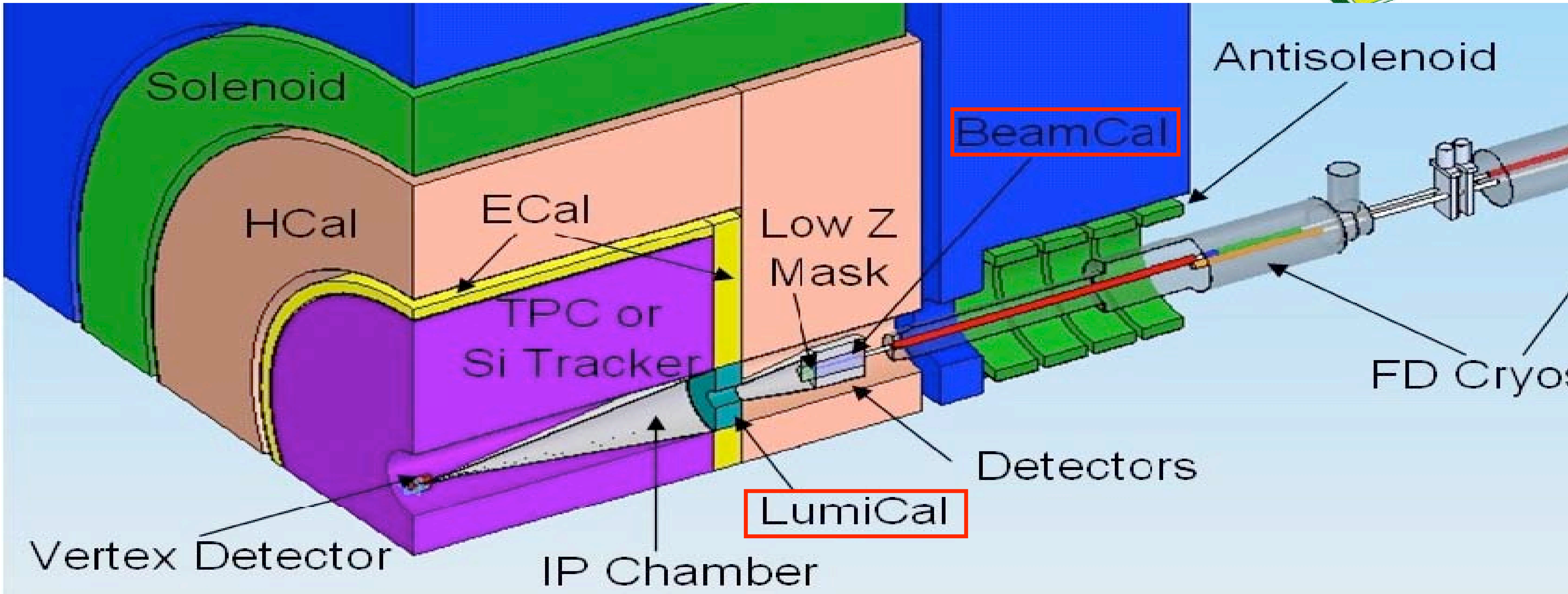
Key part of detector concept reports

Re-evaluation of all background sources
should be complete at that time

Forward Calorimeters

(Devil's playground)

Forward Calorimeters



- LumiCal - 20-50 mRad - Precision Lumi, Hermiticity (2-γ veto)
- BeamCal - 5-20 mRad - Hermiticity, Collision Diagnostics
- GamCal - 0-5 mRad - Collision Diagnostics (downstream)

Closely coupled to beam delivery system

FCAL Collaboration

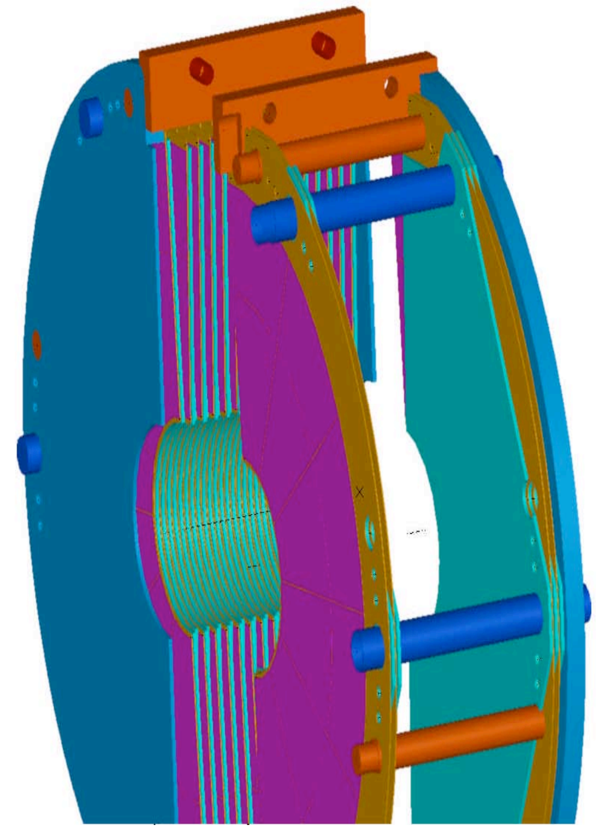
http://www.ifh.de/ILC/fcal/

US Groups: Colorado, BNL, Yale, SLAC

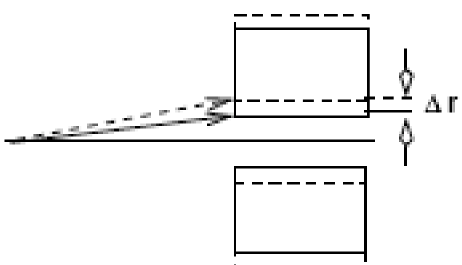
Precision Luminosity

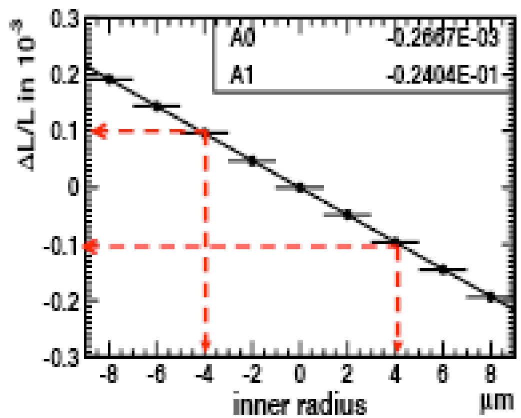
- Ambitious δL/L ~ 10^{-4} goal (Giga-Z) (theory uncertainty 5 10^{-4})
- δL/L ~ 10^{-3} probably OK for HE running

Detailed engineering/physics studies fairly mature, mostly European effort



Inner diameter of LumCal





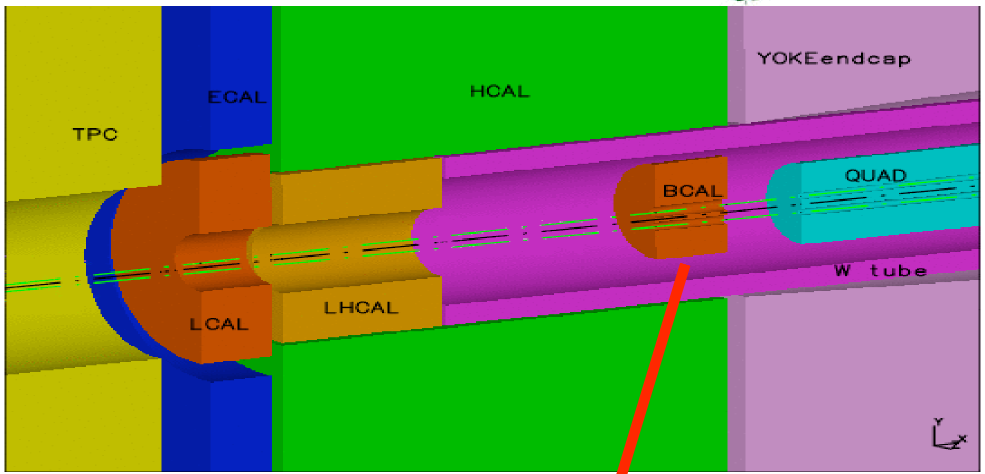
$$\frac{\Delta L}{L} \le 10^{-4} \quad \Rightarrow \Delta r \le 4\,\mu m$$

Snowmass, Aug 2005 H. Abramowicz, TAU, FCAL Coll. 6

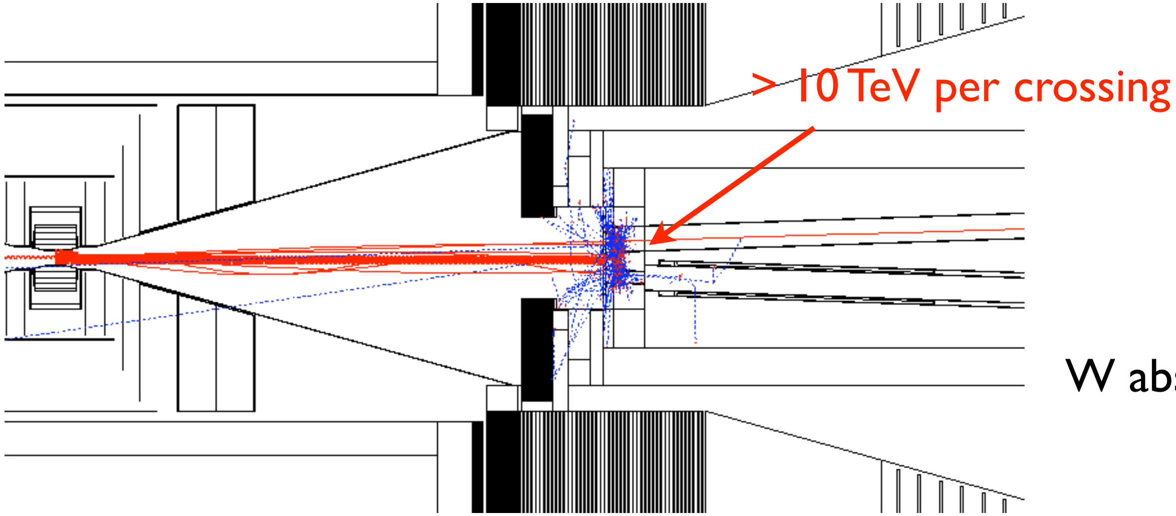
Very little US effort on specific concept implementations

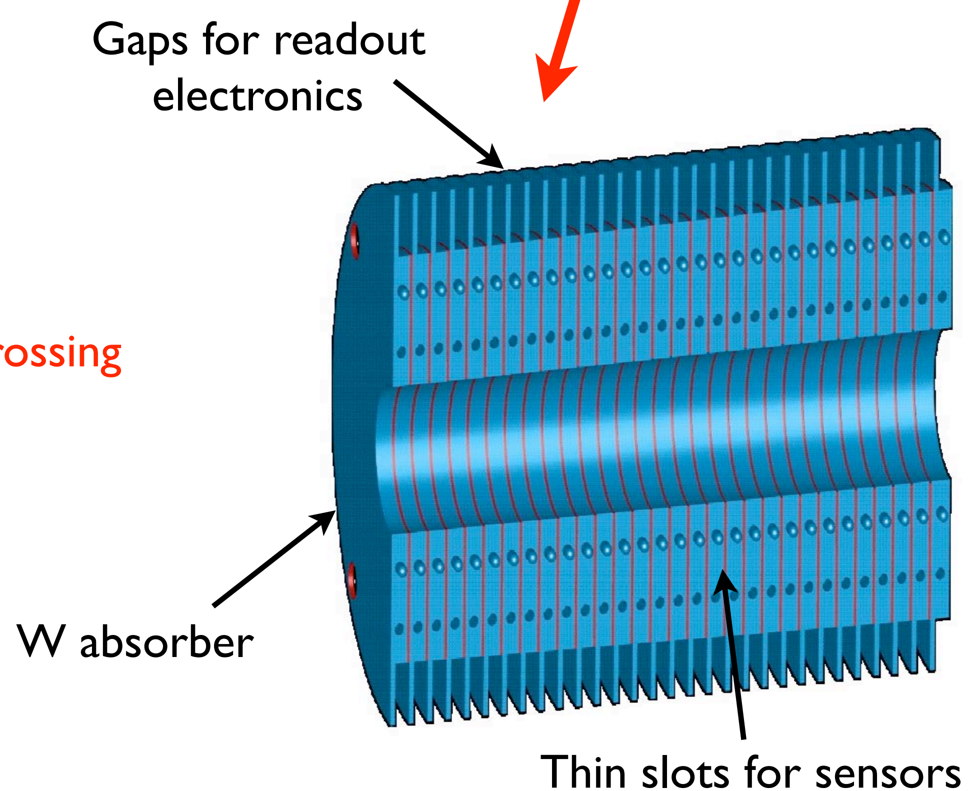
BeamCal

- Instrument pair region (5-20 mRad)
- Provide 2γ veto (e.g.: SUSY)
- Fast feedback (pair signal) for Lumi



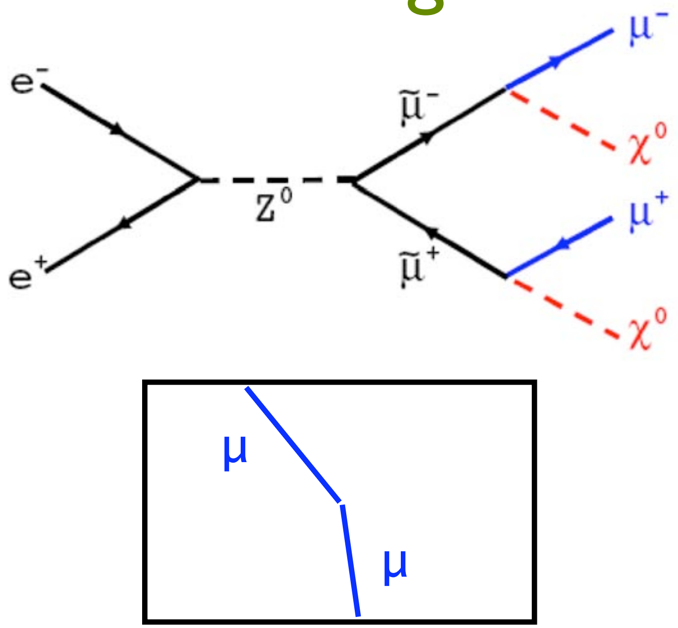
Major new challenge for ILC detectors
Need fast, very rad-hard detector with very high granularity



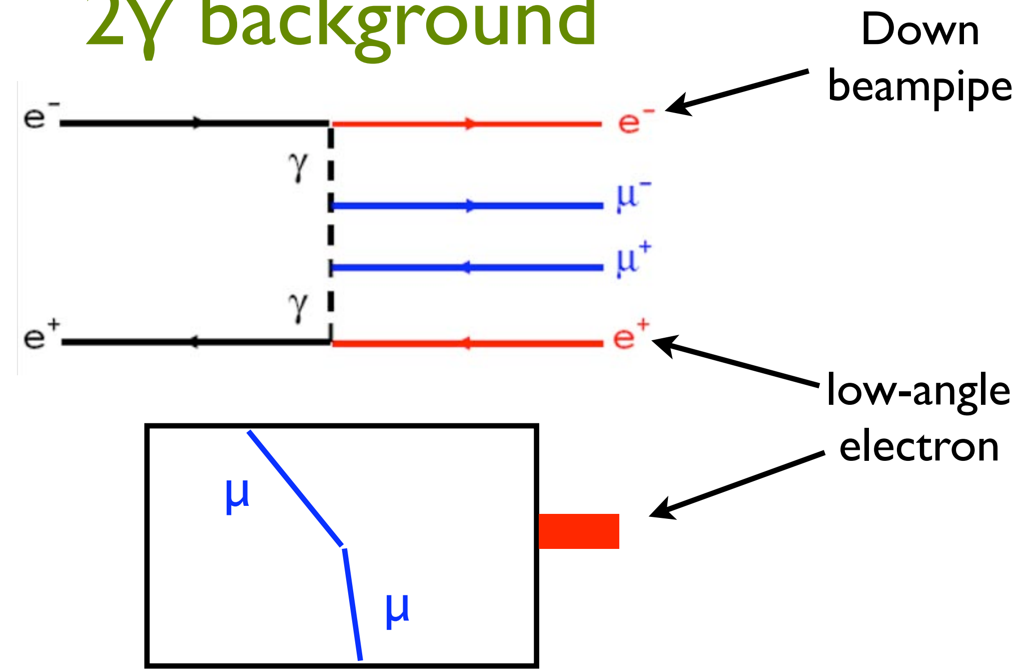


BeamCal Hermiticity

SUSY Signal



2γ background



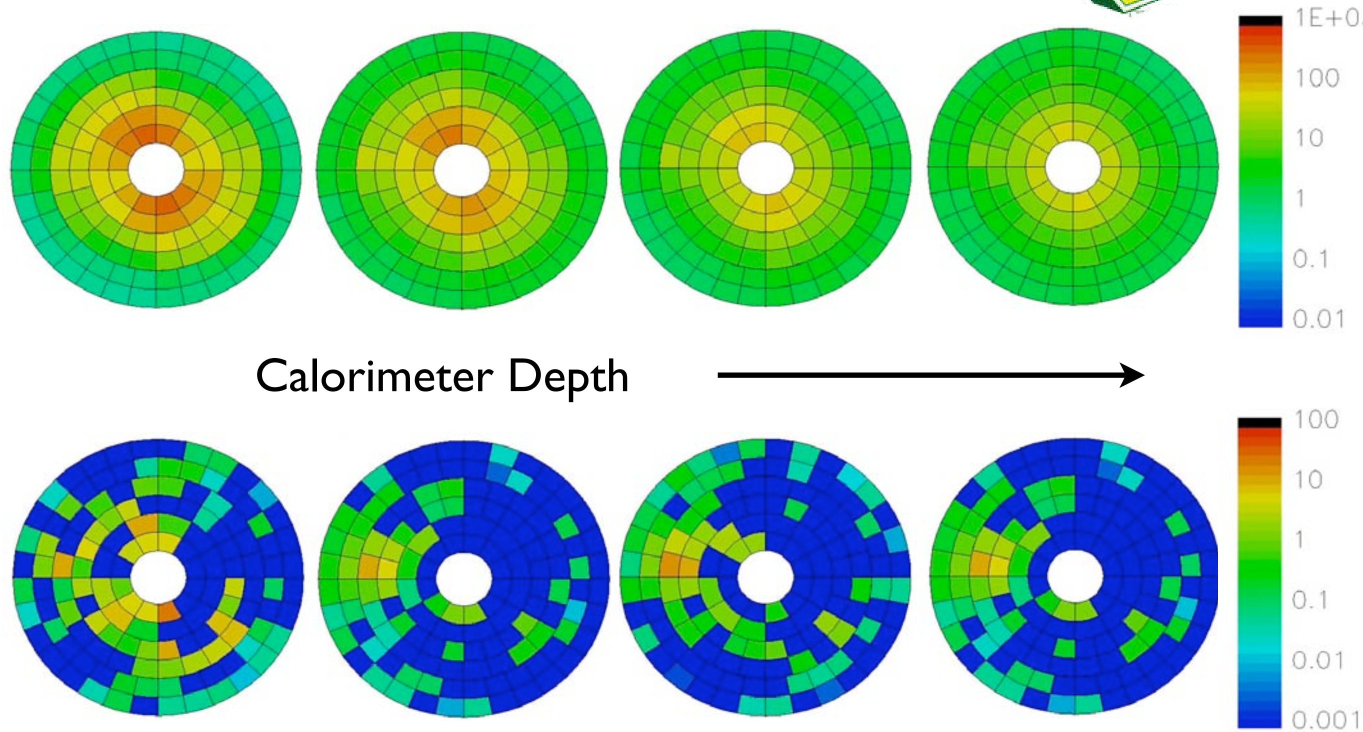
- Low-angle hermiticity key for SUSY and other analyses
- Must find electrons with very high efficiency (> 99.9%)
- SUSY ΔM reach depends upon minimum veto angle (Pt)

Also needed in LumiCal, but much easier there

Electron Signature

20 TeV Pair Background

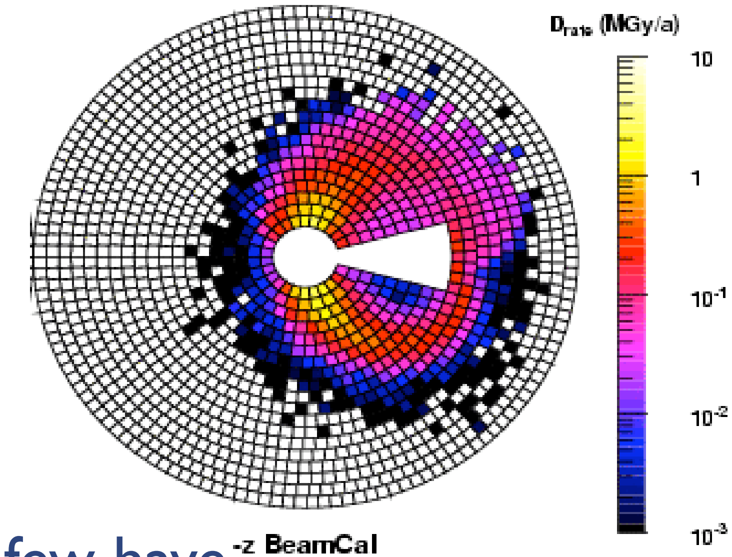
250 GeV electron
(background subtracted)



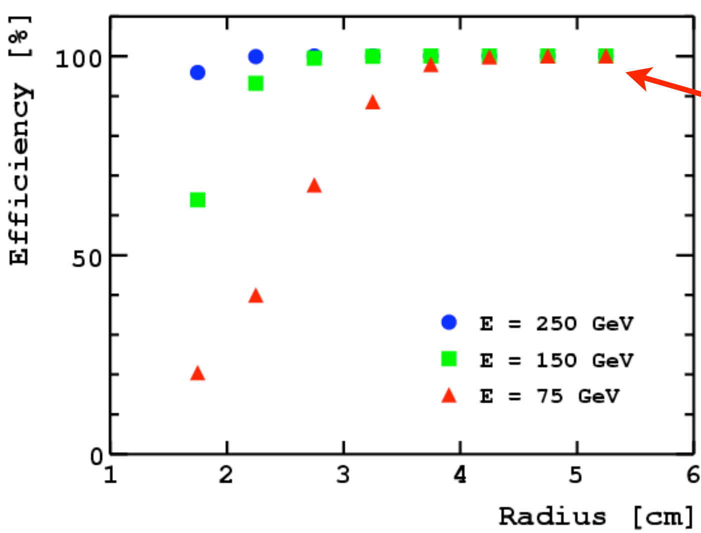
- Rely on high granularity, high segmentation
  30 layers 1 X_0, ~(5 mm)^2 pixels (order 50k channels x2)
- Must readout every pulse (3 MHz)
- Must correct pair fluctuations on every pulse

Electron Efficiency Studies

- Shape varies due to collision parameters, magnetic fields (solenoid + DID)
- Results sensitive to exact detector geometry



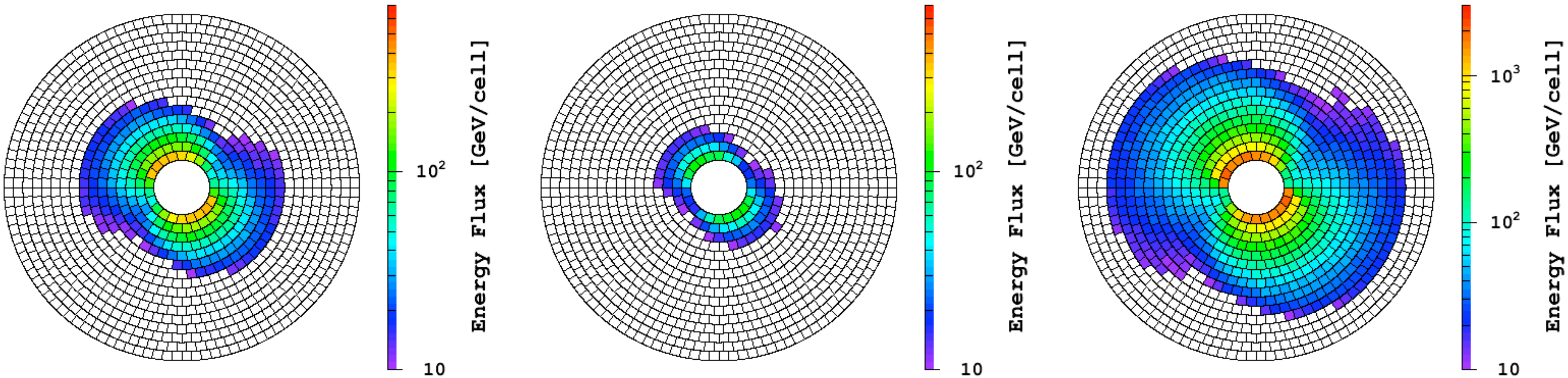
Many studies done, few have realistic field maps, detector geometries, and collision variations



Need factor ~1000 2γ rejection
Eff > 99.9% needed in plateau

Bhabha and hadronic 2γ backgrounds also problematic for electron (mis-)ID

Machine Conditions



Nominal | Low Q | High Lumi

- Pair distribution highly dependent upon collision parameters
- Useful as a machine diagnostic (extract collision parameters)
- Realistic variation must be incorporated into physics studies

Colorado group has started doing good work here with G4 sim

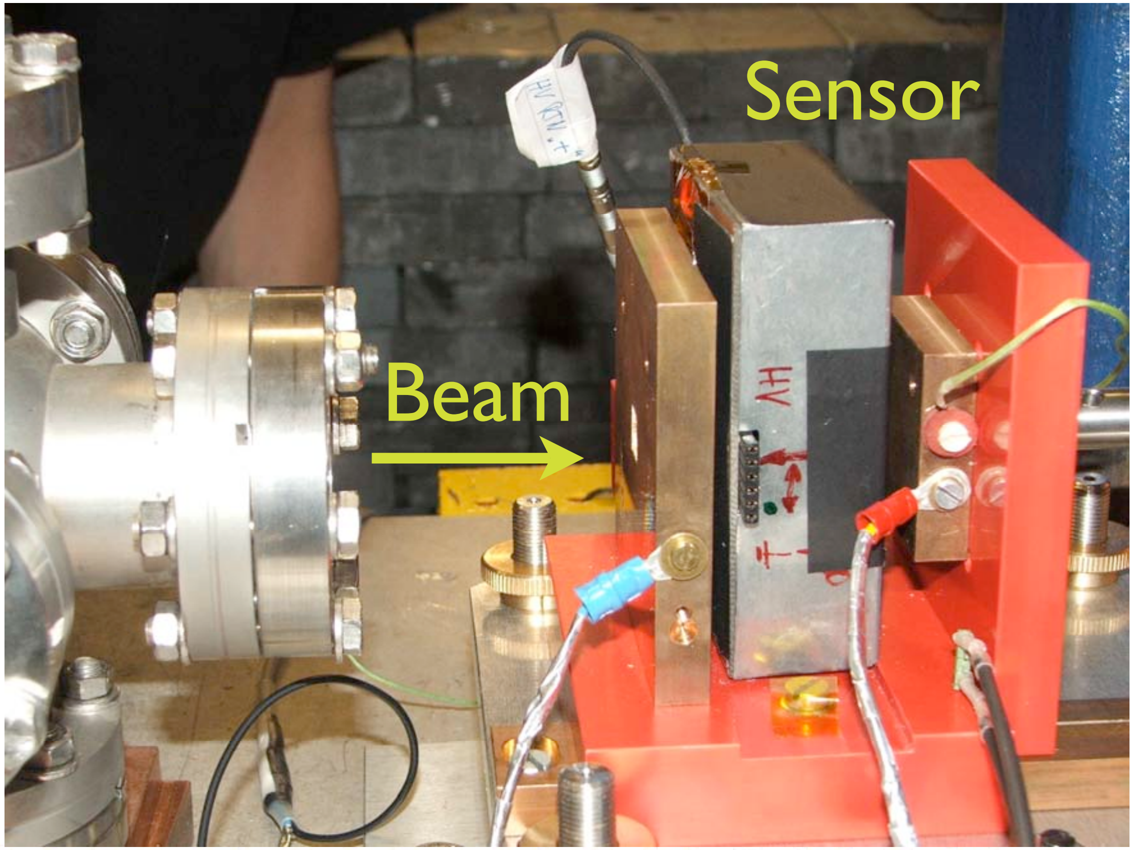
Sensor Development

- Need very rad-hard sensor - expect 2-10 MGy/year
- Need high segmentation, fast readout
- Many sensors considered:
  pCVD diamonds, rad-hard Si, GaAs, ...

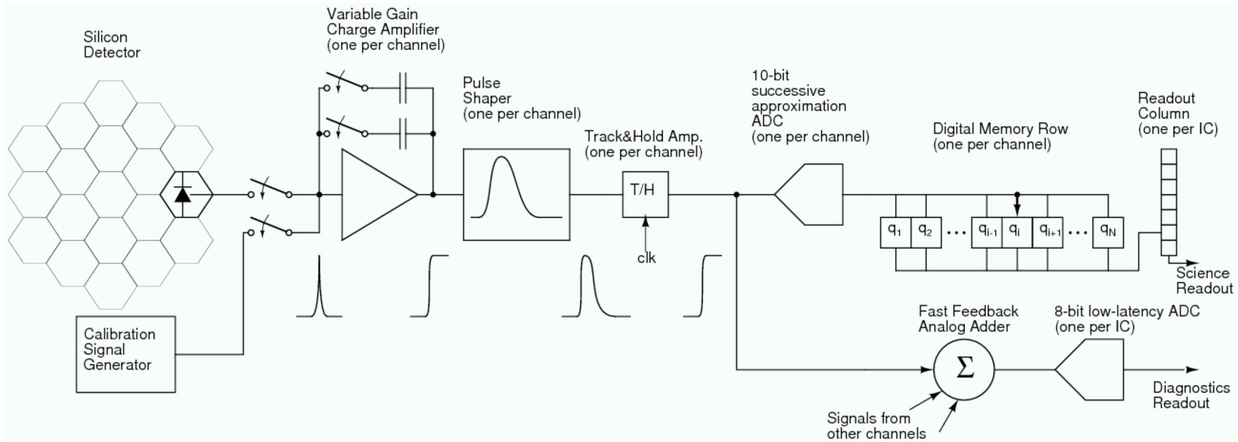
Active beam tests at Darmstadt (10 MeV e^-), mostly European

Early favorite (diamond) show "interesting" behavior...

Field is wide open!
BNL starting some work here, plenty of room for other groups with experience to get involved



Electronics/DAQ

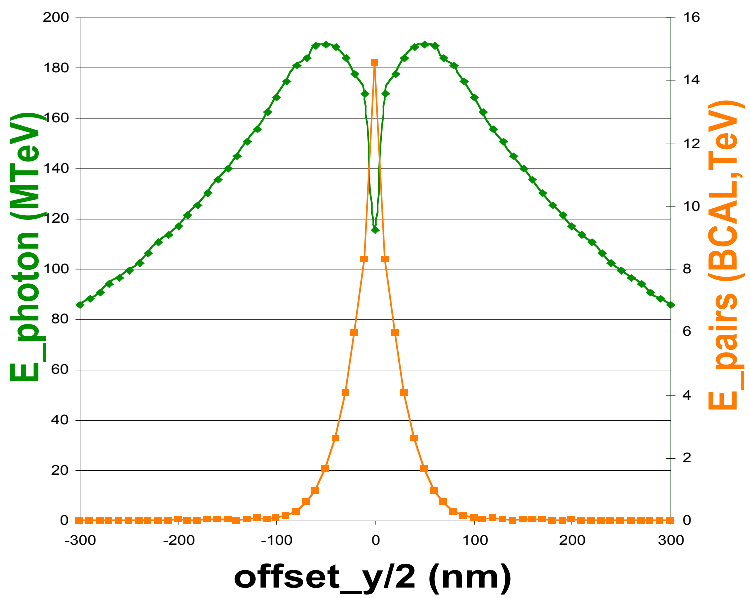


- SLAC modifying Kpix (calorimeter) readout chip for front-end Lumical/Beamcal use (save every BX)
- DAQ/FEX clearly an interesting (uncovered) problem
  - Full readout unrealistic/undesired? Use FPGA-based FEX
  - Provide lumi feedback at 4 MHz, reduced granularity
  - Develop real-time e- trigger, trigger partial readout?

About the only bona-fide detector trigger design challenge at the ILC

GamCal

E_pairs (BCAL) and E_photon



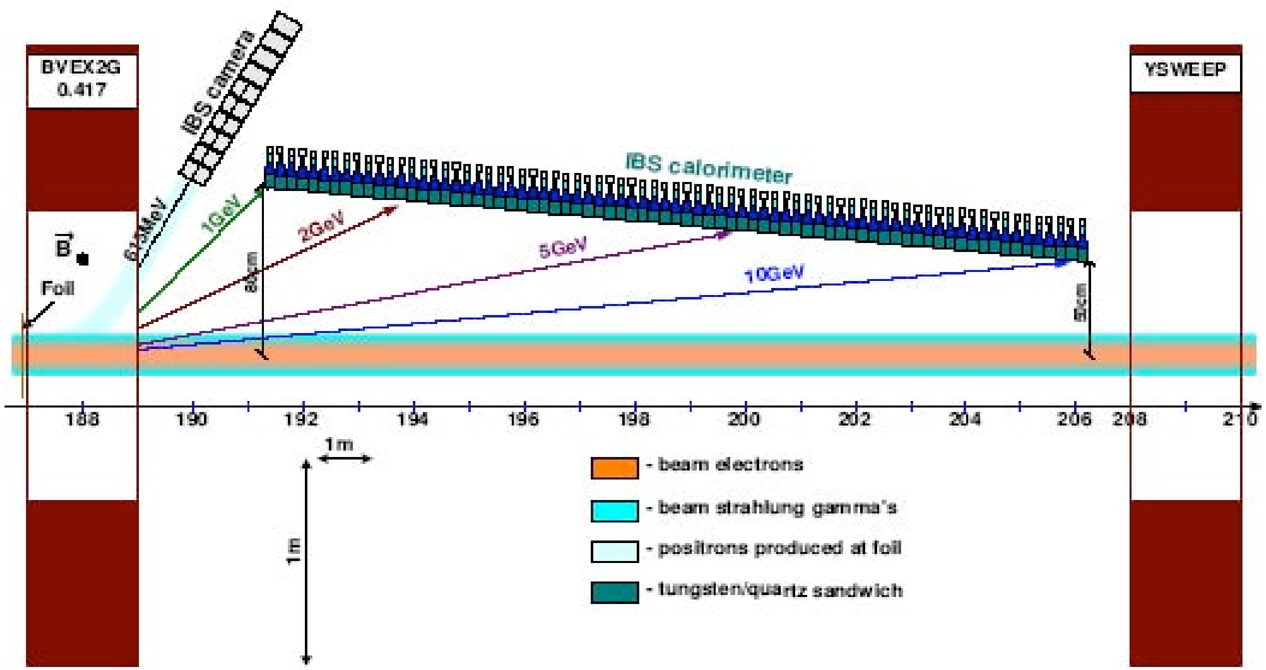
Yale proposal for converting photons downstream (GamCal)

BSL photon energy and pair energy

Ratio E_{γ}/E_{pair} gives much better instantaneous luminosity estimate

BNL (Morse)/Yale looking at this

Consider using Rad Bhabhas also?



Beam Instrumentation

(Energy, Polarization, Luminosity)

Precision Electroweak

- m_Z, Γ_Z (LEP I)

  Energy, Lumi

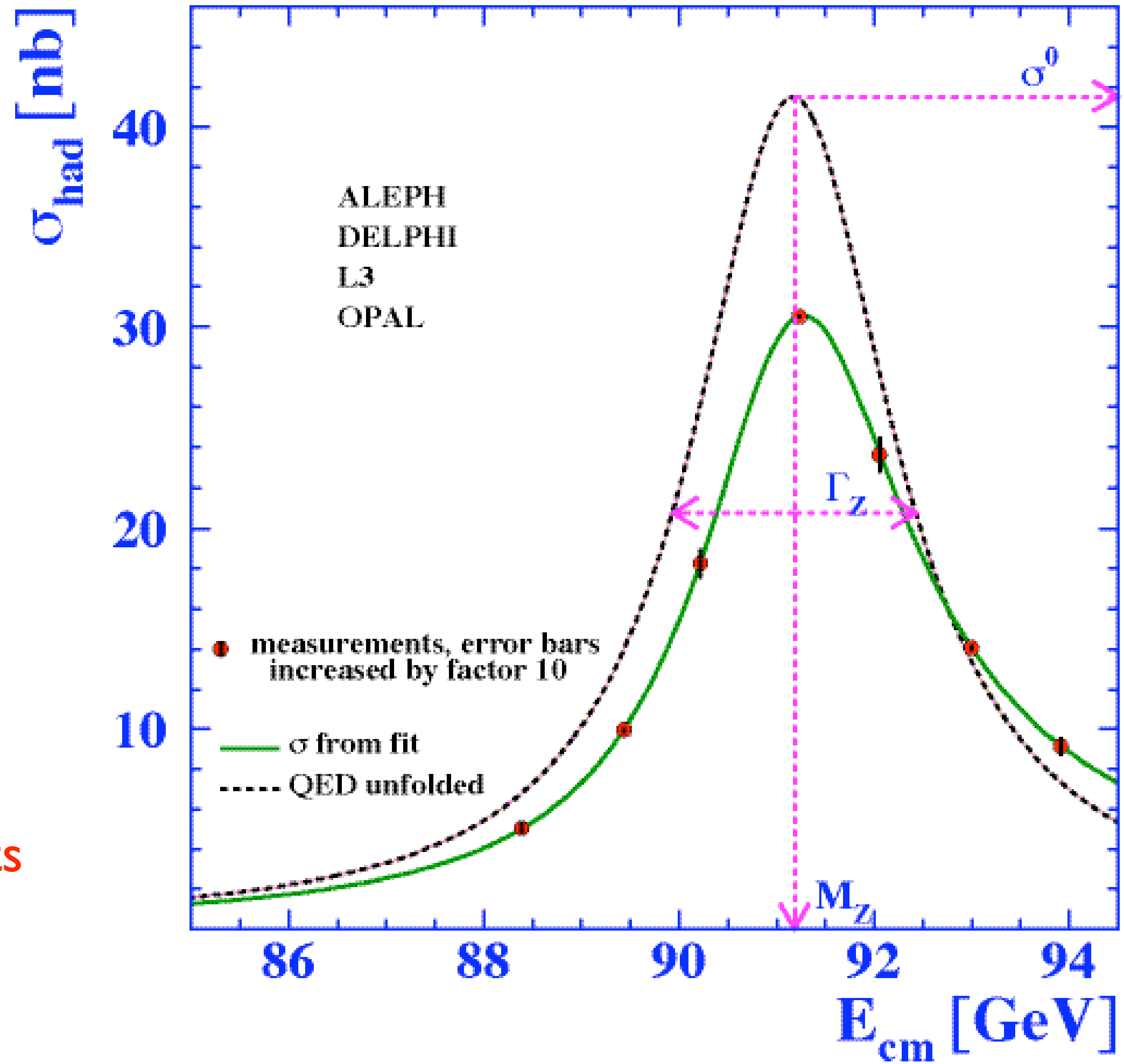
- m_W (LEP II)

  Energy

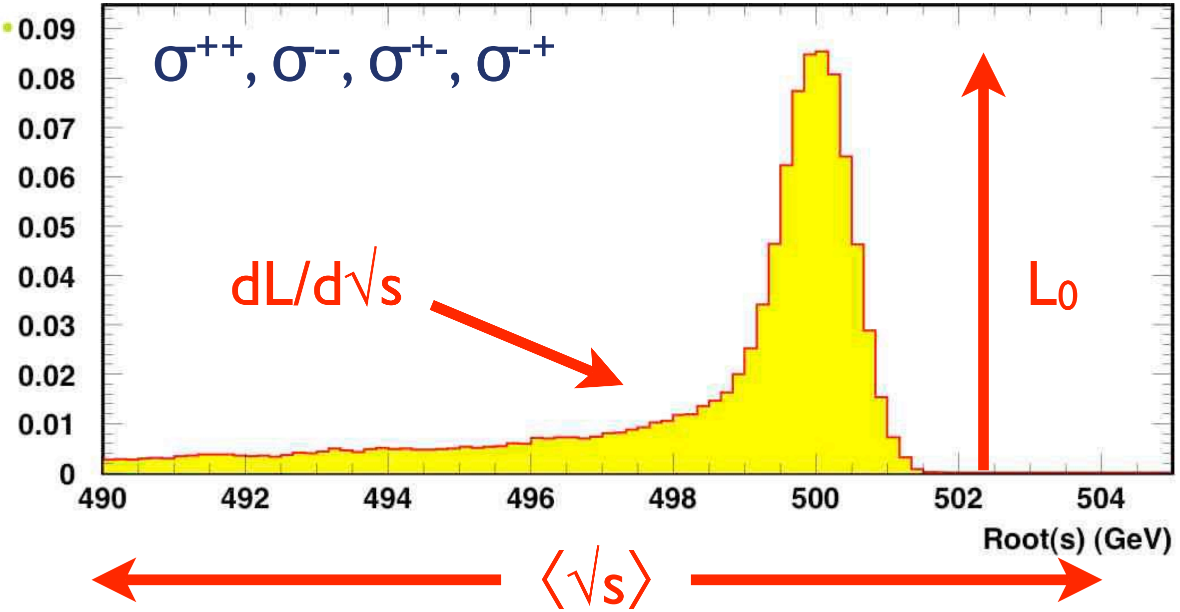
- $\sin^2\Theta_W$ (SLC)

  Polarization

Precision measurements in e^+e^- depend on beam instrumentation



IP Instrumentation



Fundamental IP Beam Instrumentation Goal:

Spin-dependent absolute collision energy spectrum

Typical Ingredients:

Beam Energy, Energy Width
Beam Polarization, Asymmetries
Absolute Luminosity, Differential Spectrum

Mix of physics and beam measurements

Instrumentation Goals

Beam Energy

- $\langle\sqrt{s}\rangle$ understood to 100-200 ppm

Motivated by m_t, m_H, m_X uncertainties ~ 50-100 MeV

Beam Energy necessary, but not sufficient!
Luminosity spectrum also important

Polarization

- $\delta P/P$ ~ 0.25% goal, could use better

Positron polarization helps considerably!

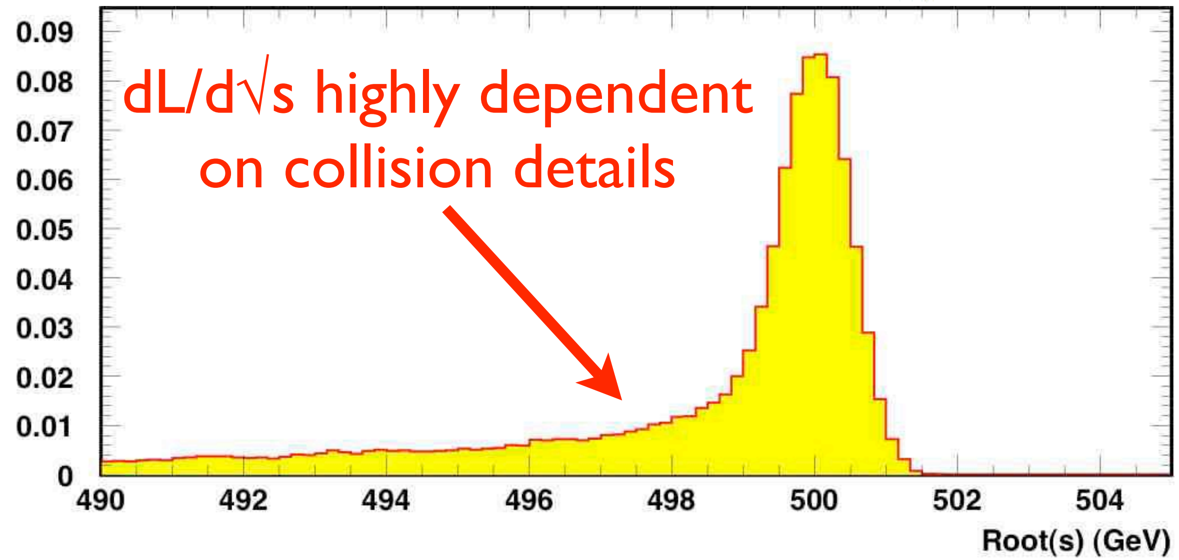
Absolute Luminosity

- $\delta L/L$ ~ 0.01% FCAL goal (hard)
  $\delta L/L$ ~ 0.1% probably OK for HE program ("easy")

Instrumentation Strategy

Why is this hard?

Need lumi-weighted quantities, depend upon correlations, variations in lumi spectrum



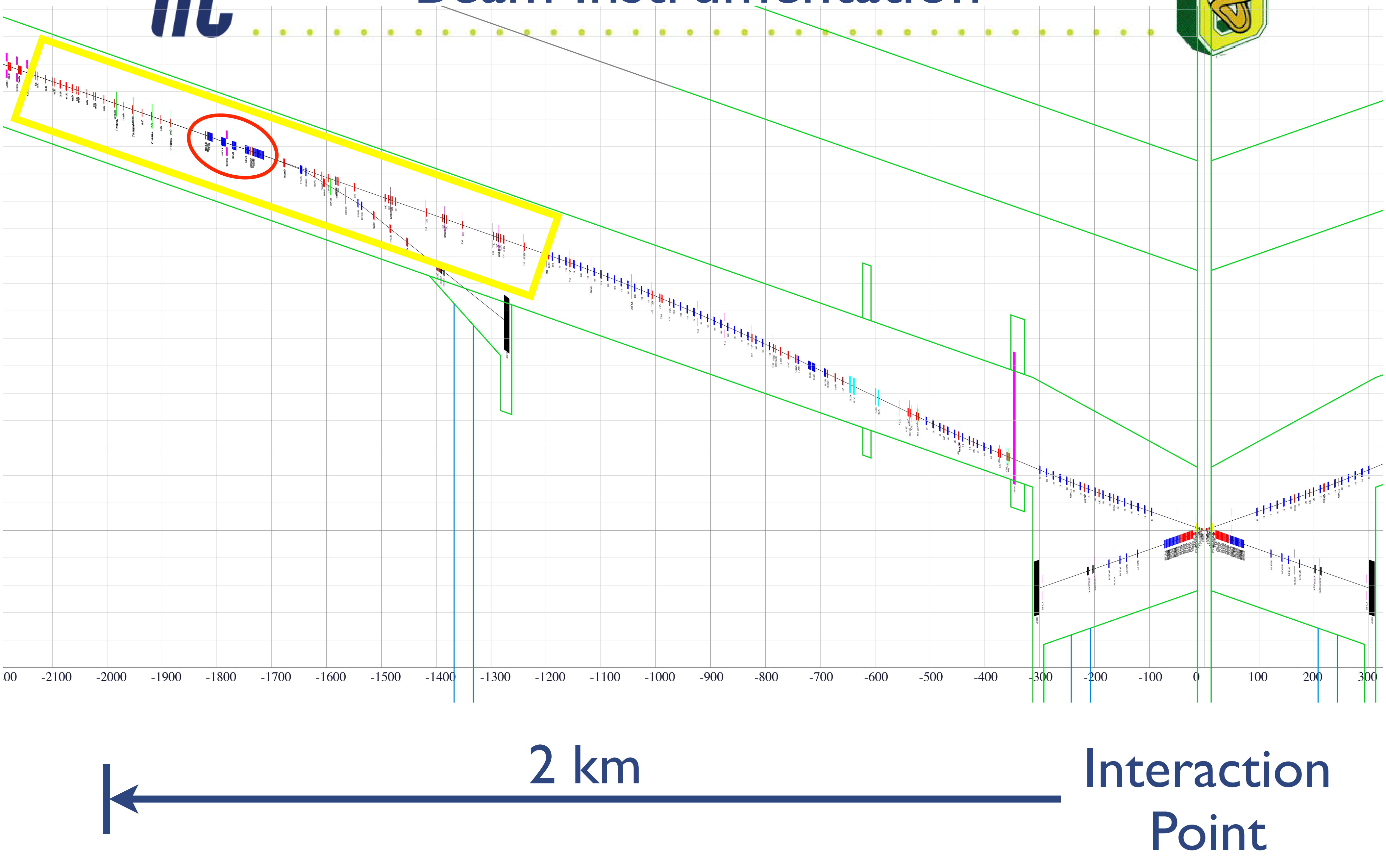
Beam Instrumentation

- Redundant, precise beam instrumentation
- Fast response to track variations

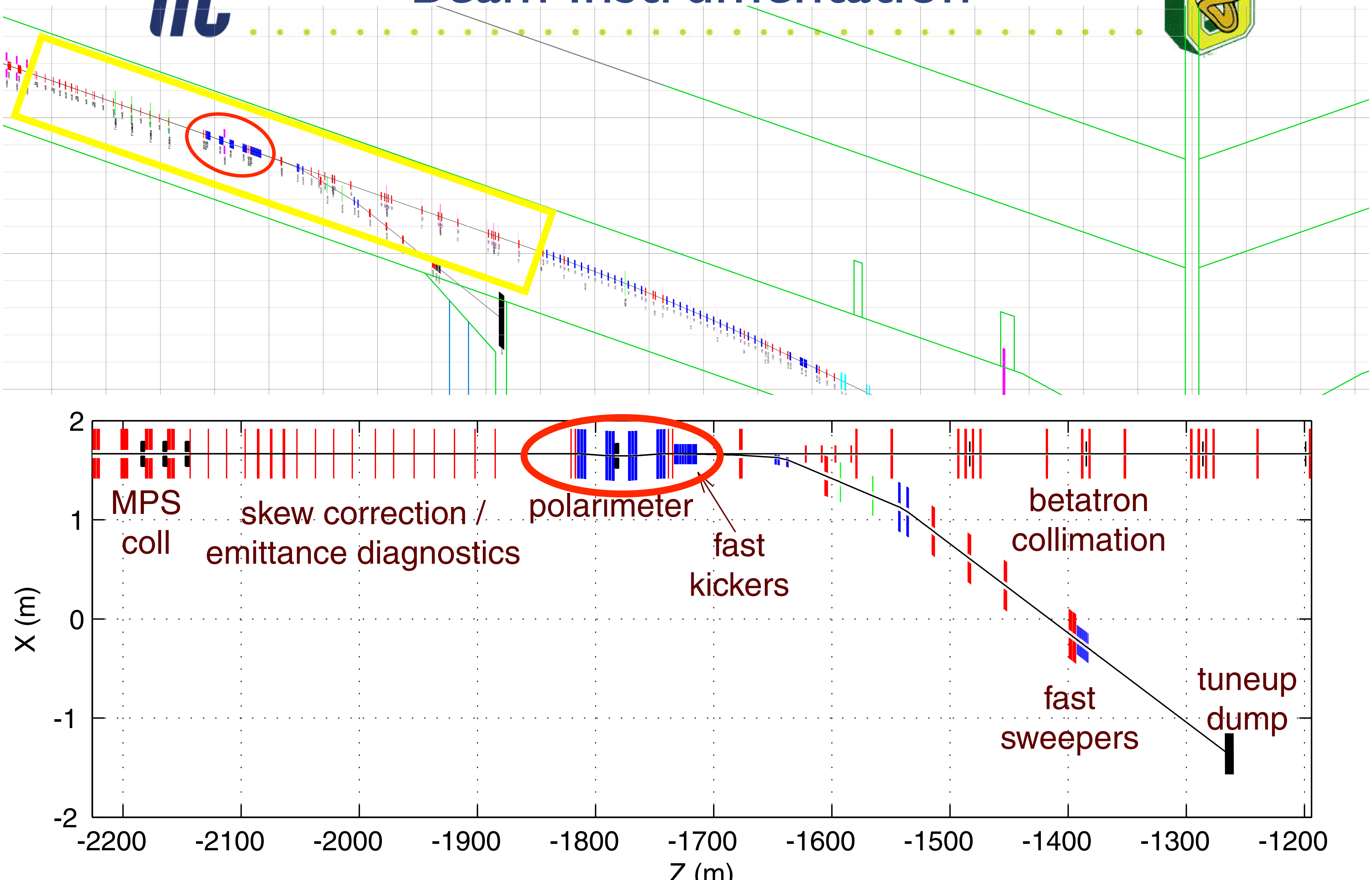
Physics Reference Reactions

- Cross-check or calibrate with sensitive physics measurements
- Ideally cross-check with similar precision

Beam Instrumentation

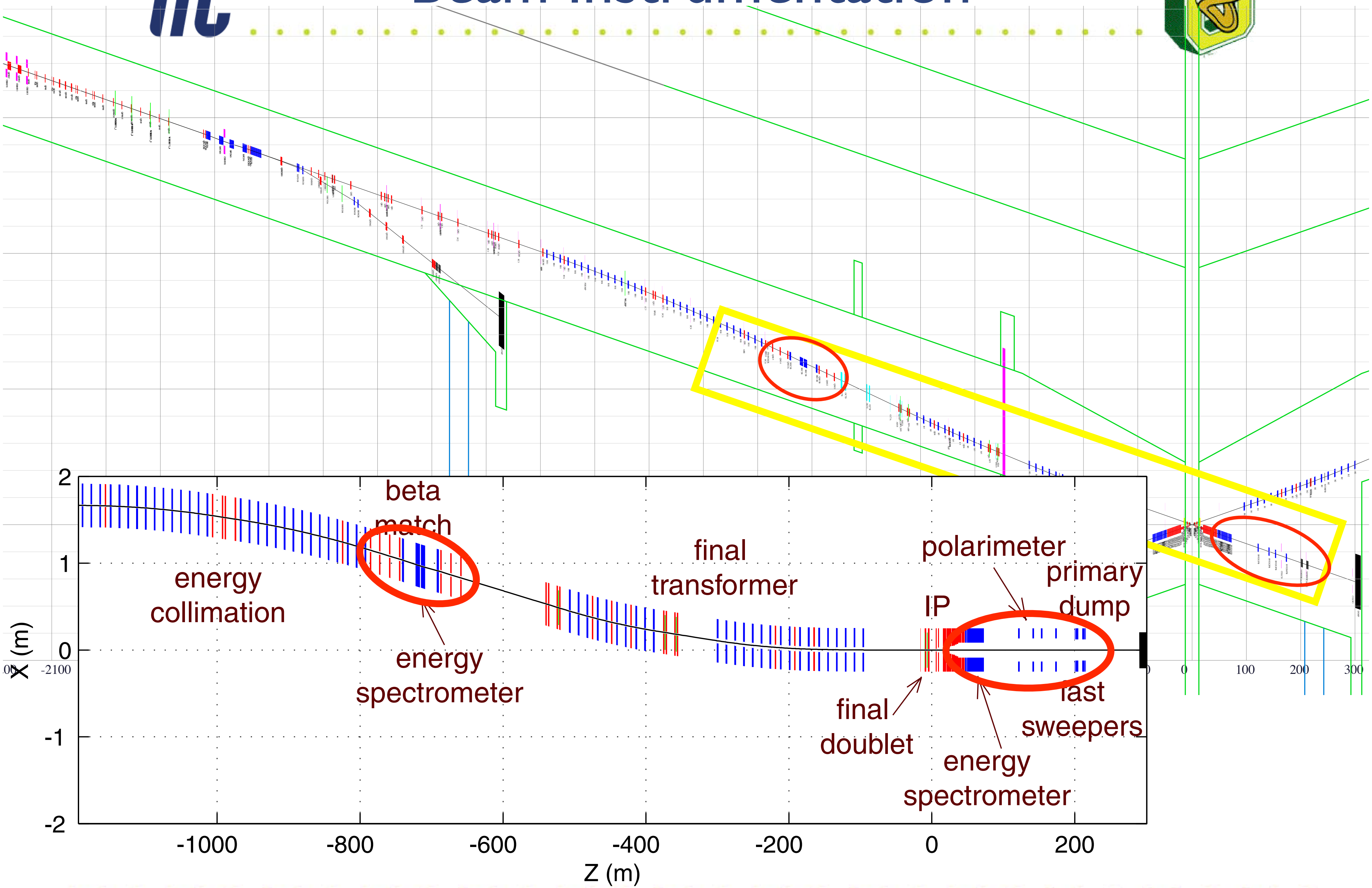


Beam Instrumentation

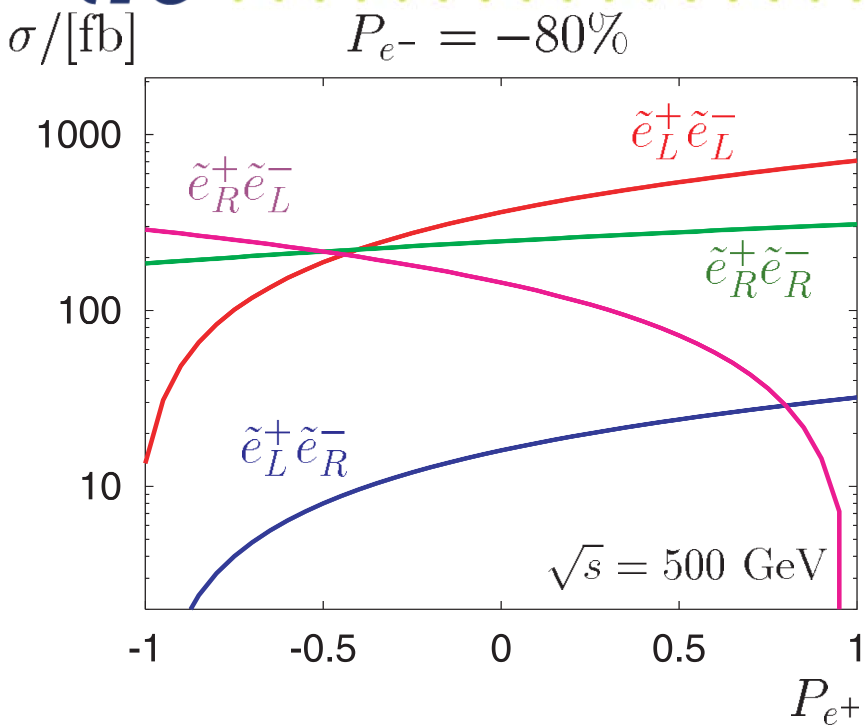


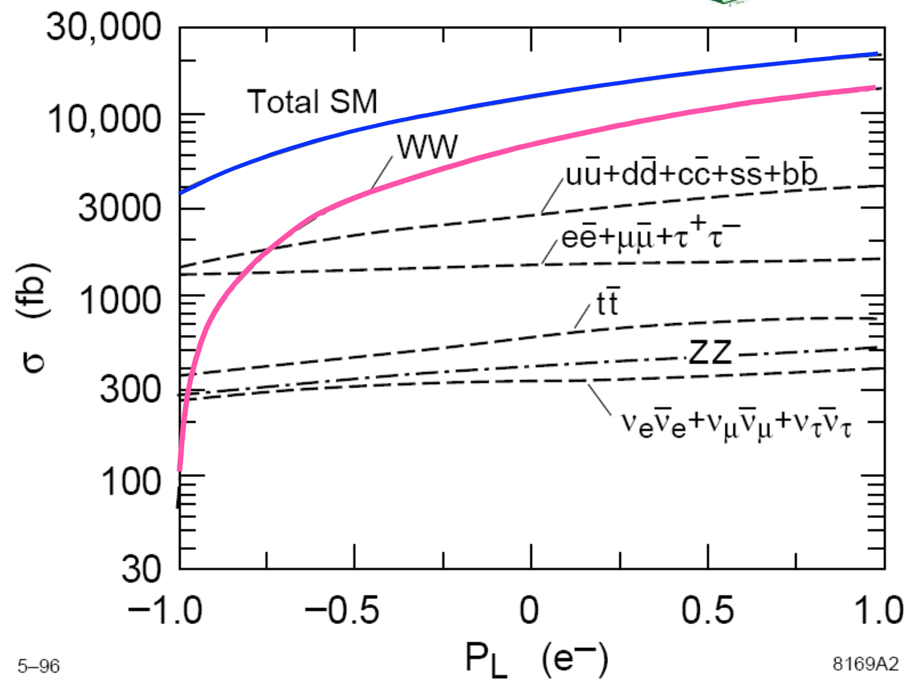
Beam Instrumentation

Beam Instrumentation



Polarization Physics





- Dis-entangle helicity states in new processes (e.g.: SUSY)
- Background suppression (WW)
- Precision EW (GigaZ)

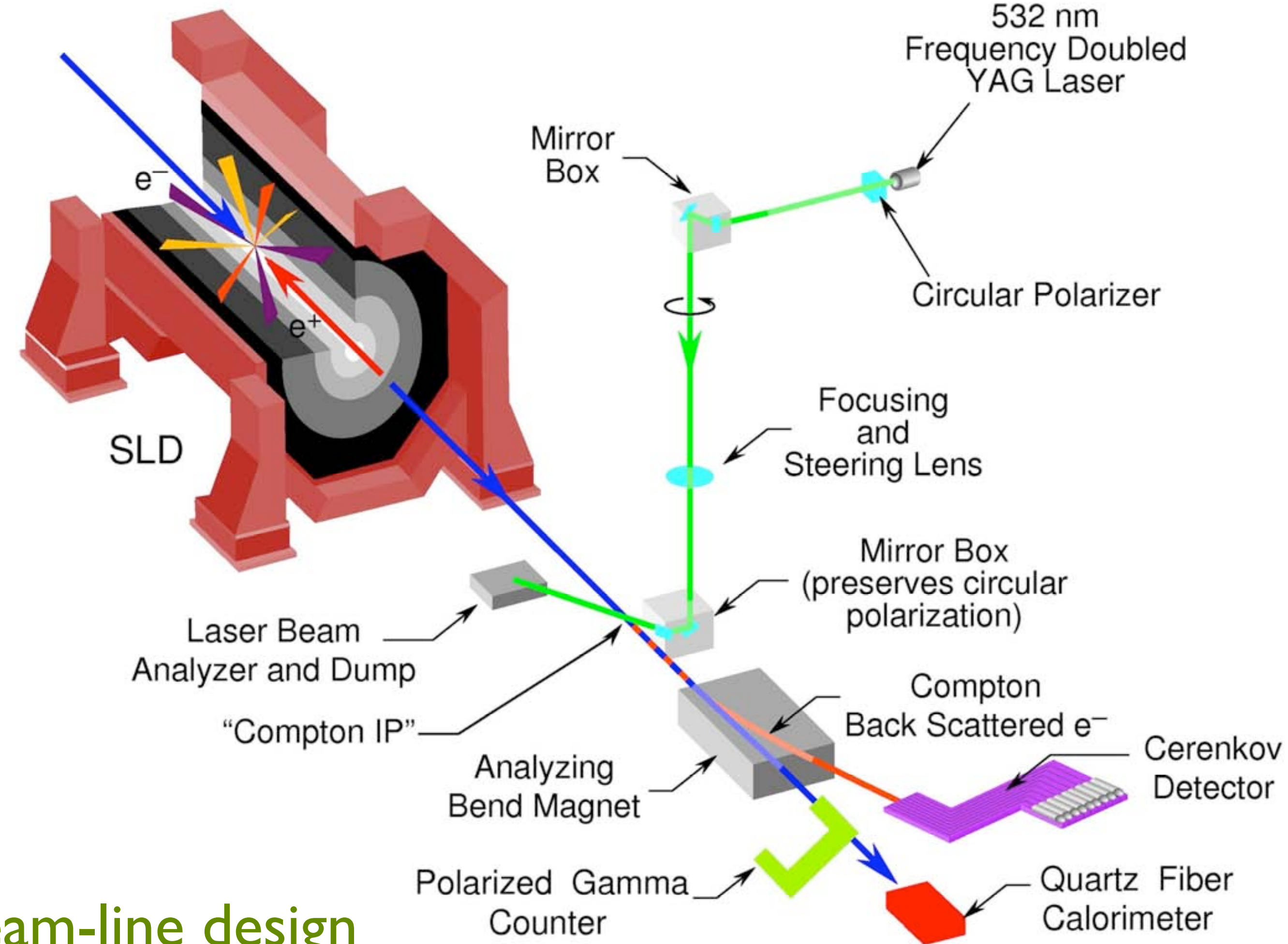
Precision polarization key component of ILC physics

Polarization

- δP/P ~ 0.25% goal
- Reasonable extrapolation of SLC experience
- Positron polarization helps tremendously:

$$P_{eff} = \frac{P_- + P_+}{1 + P_- P_+}$$

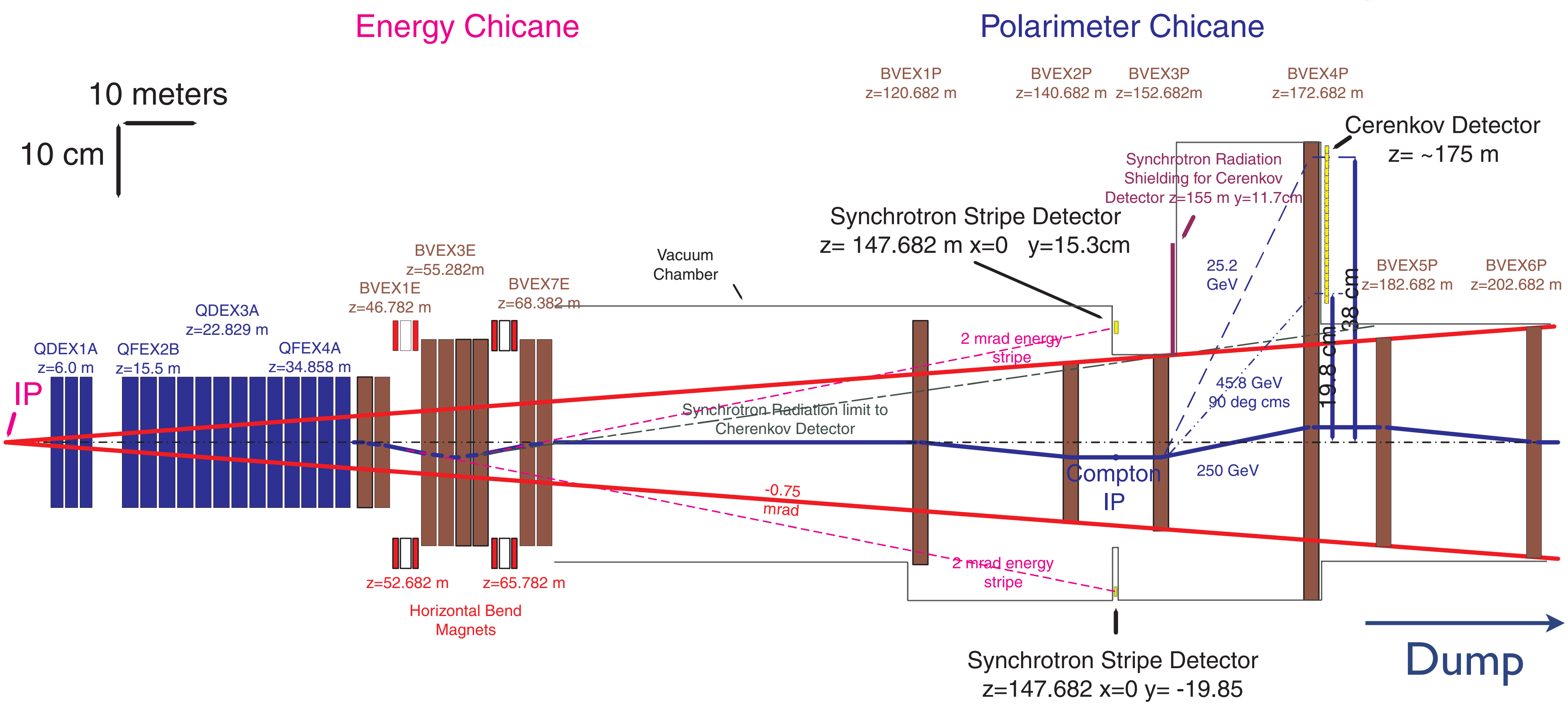
$\delta P_{eff}/P_{eff} \sim 0.10\%$
Use Blondel scheme for absolute scale



Current work largely on beam-line design
Some studies on improving detectors

Upstream spectrometer - largely DESY design
Downstream spectrometer - largely SLAC design

Downstream extraction line



Designs rather advanced
Next round is detailed engineering for EDR

Beam Energy

Beam Energy Needs

- Target 100-200 ppm from 2 m_t < $\sqrt{s}$ < 1 TeV

Motivated by Δm_t, Δm_W ~ 50 MeV

- Recognize desire for 50 ppm at m_Z - 2 m_t

"Giga-Z" precision EW

Energy Proposal

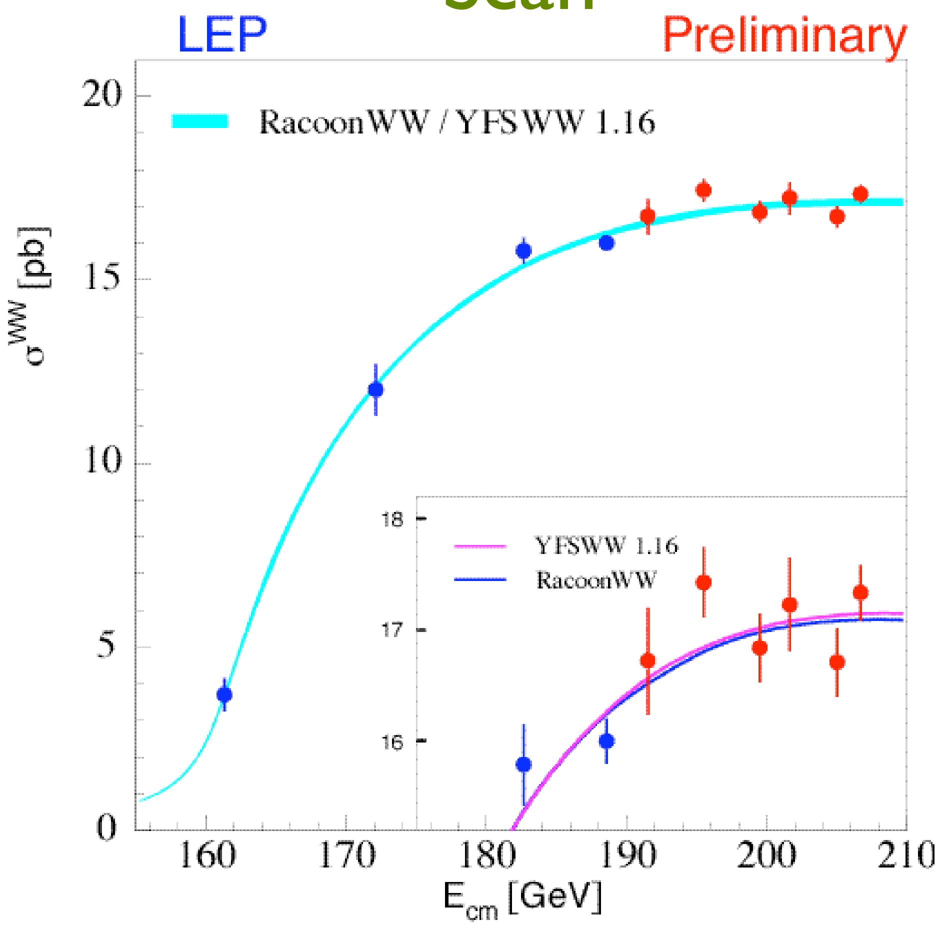
- BPM-style upstream spectrometer (LEPII)
- WISRD-style downstream spectrometer (SLC)
- Physics reference reactions (e.g.: $e^+e^- \rightarrow Z\gamma$)

Mix of physics-based and beam-based measurements

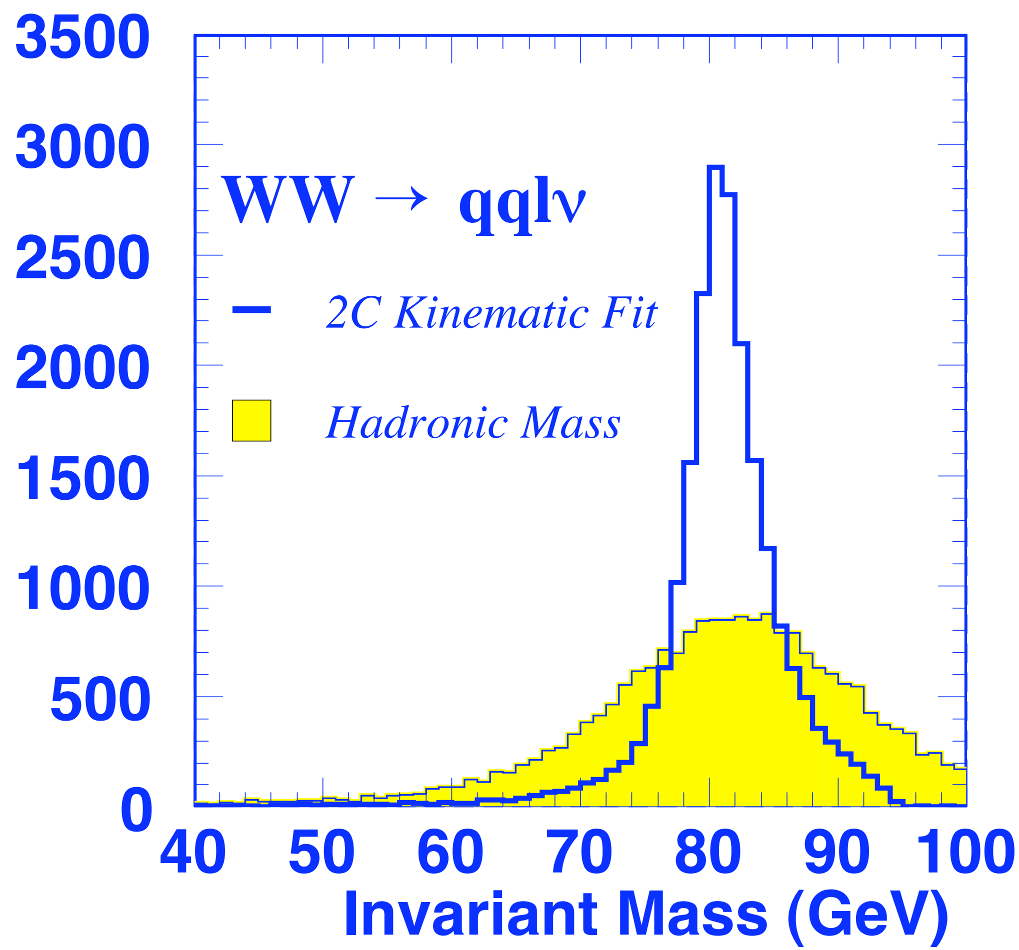
Need good forward tracking (200-500 mRad)

LEP II W Mass

Lineshape Scan



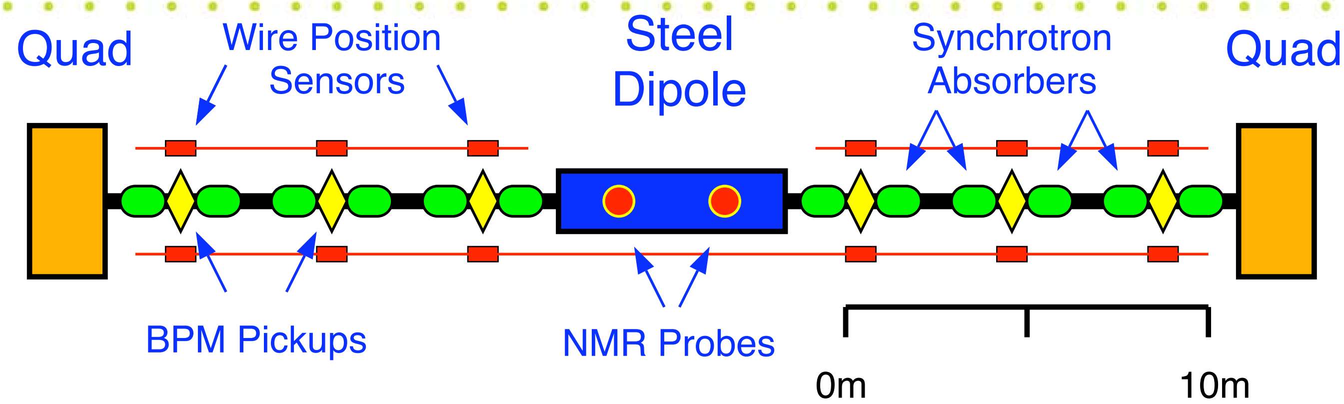
Direct Reconstruction



Both rely on knowing collision energy

BPM-based spectrometer

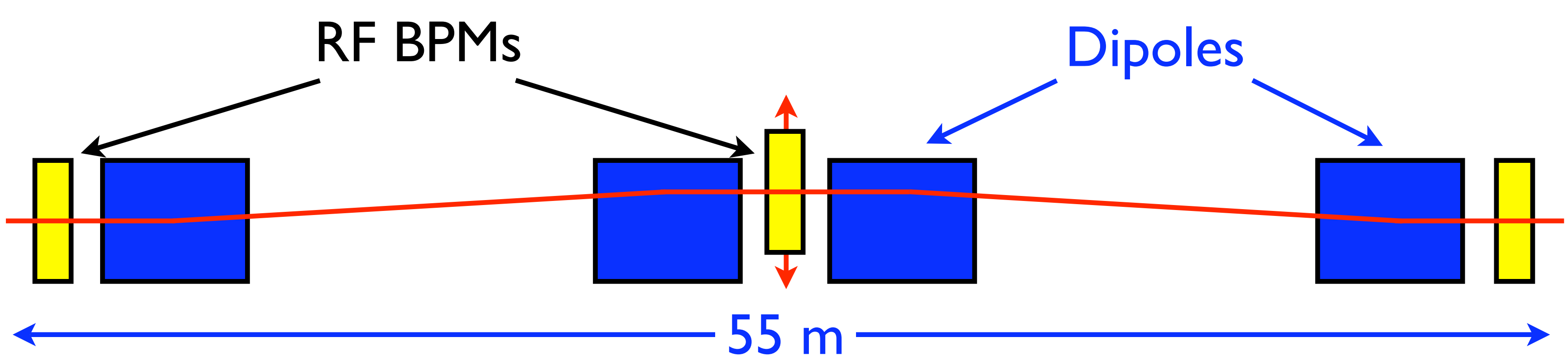
LEP II



4.8 mRad bend, 1 micron BPM accuracy, < 8 hour stability

200 ppm relative measurement achieved

ILC

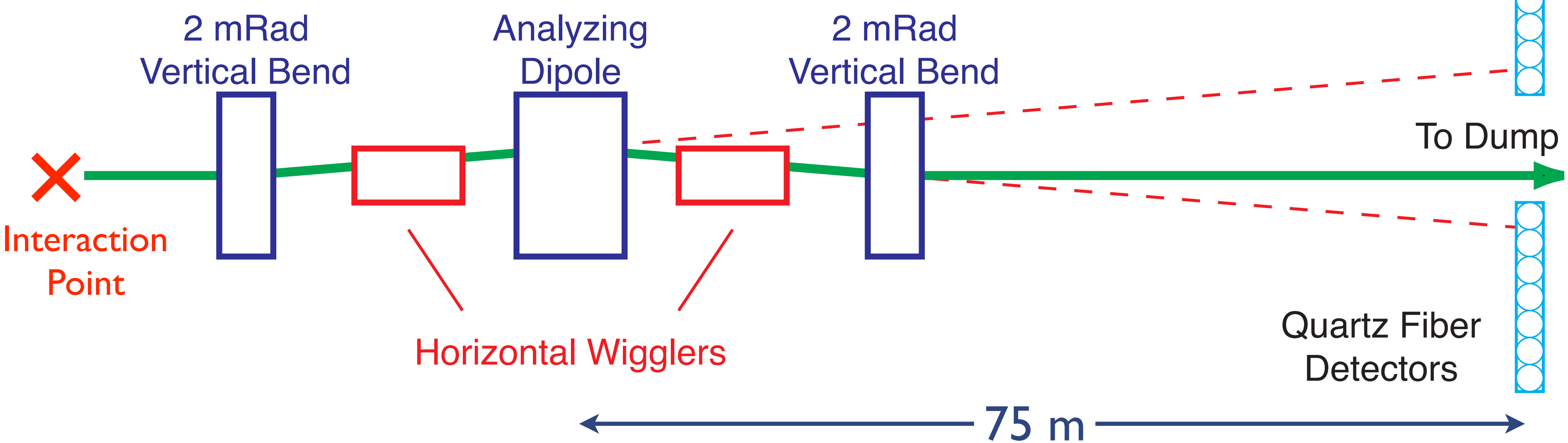


200 μRad bend, 500 nm BPM accuracy (emit. growth)

move the BPM to the beam, in situ calibration

aim for 100 ppm absolute

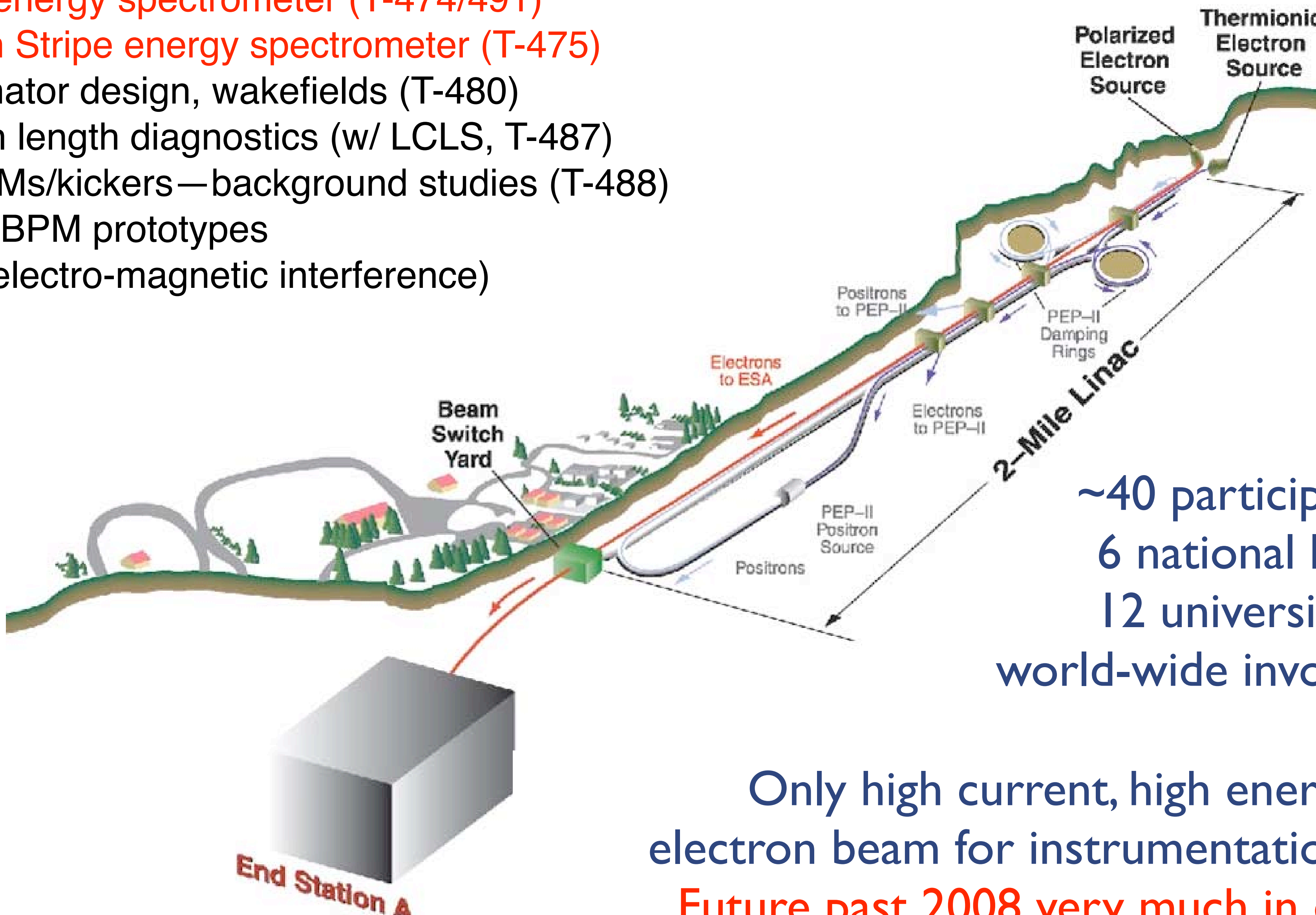
Wisrd-Style Spectrometer



- Detect SR photons on quartz fiber array (~150 µm pitch)
- ±2 mRad bend over 75 m → 125 MeV/100 µm
- Need transverse accuracy of 30 µm at detector plane
- Measure mean beam energy and disrupted tail spectrum

SLAC ESA Program

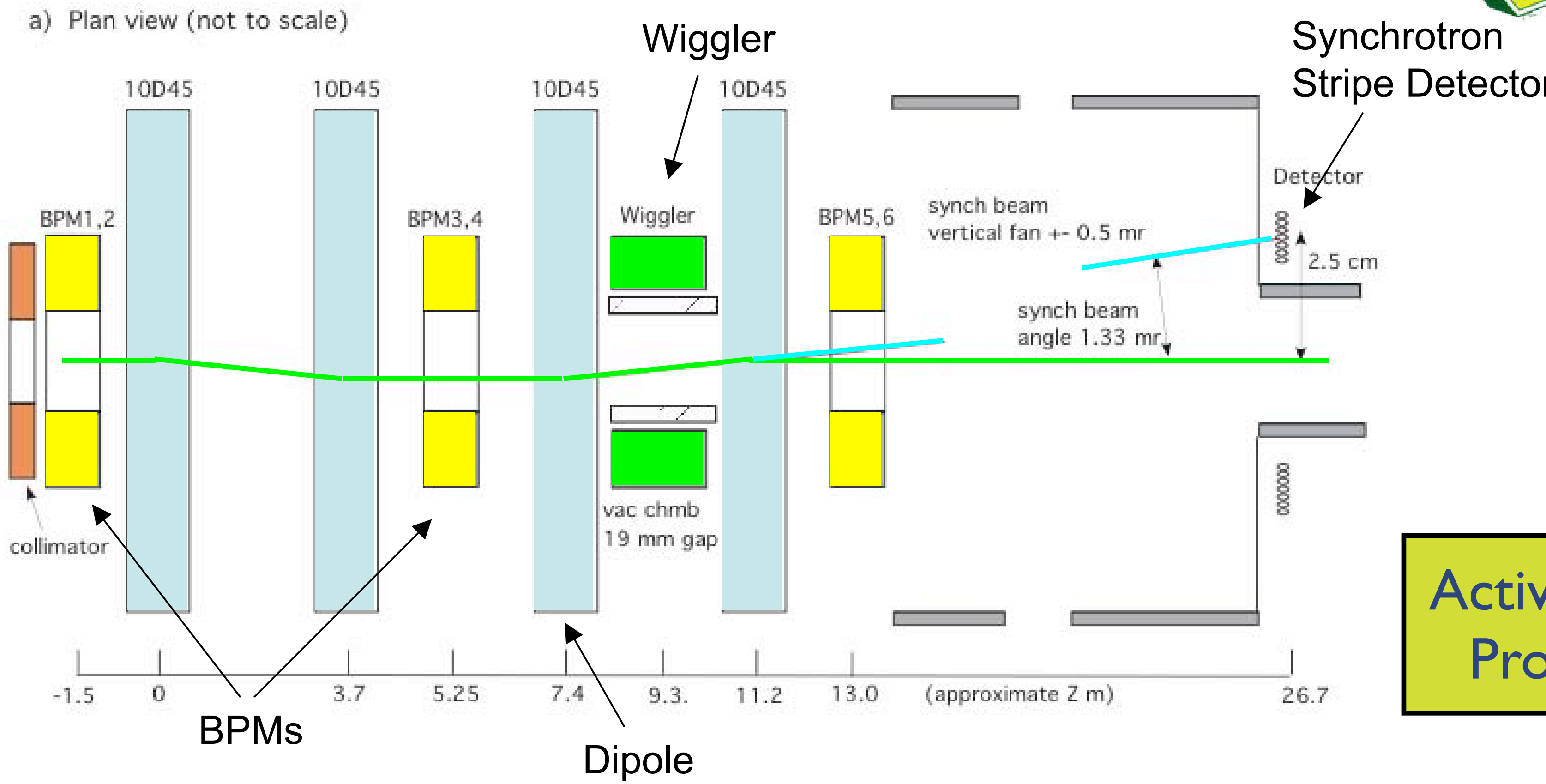
BPM energy spectrometer (T-474/491)
Synch Stripe energy spectrometer (T-475)
Collimator design, wakefields (T-480)
Bunch length diagnostics (w/ LCLS, T-487)
IP BPMs/kickers—background studies (T-488)
Linac BPM prototypes
EMI (electro-magnetic interference)



~40 participants
6 national labs
12 universities
world-wide involvement

Only high current, high energy electron beam for instrumentation tests
Future past 2008 very much in doubt

Spectrometer Testbeams



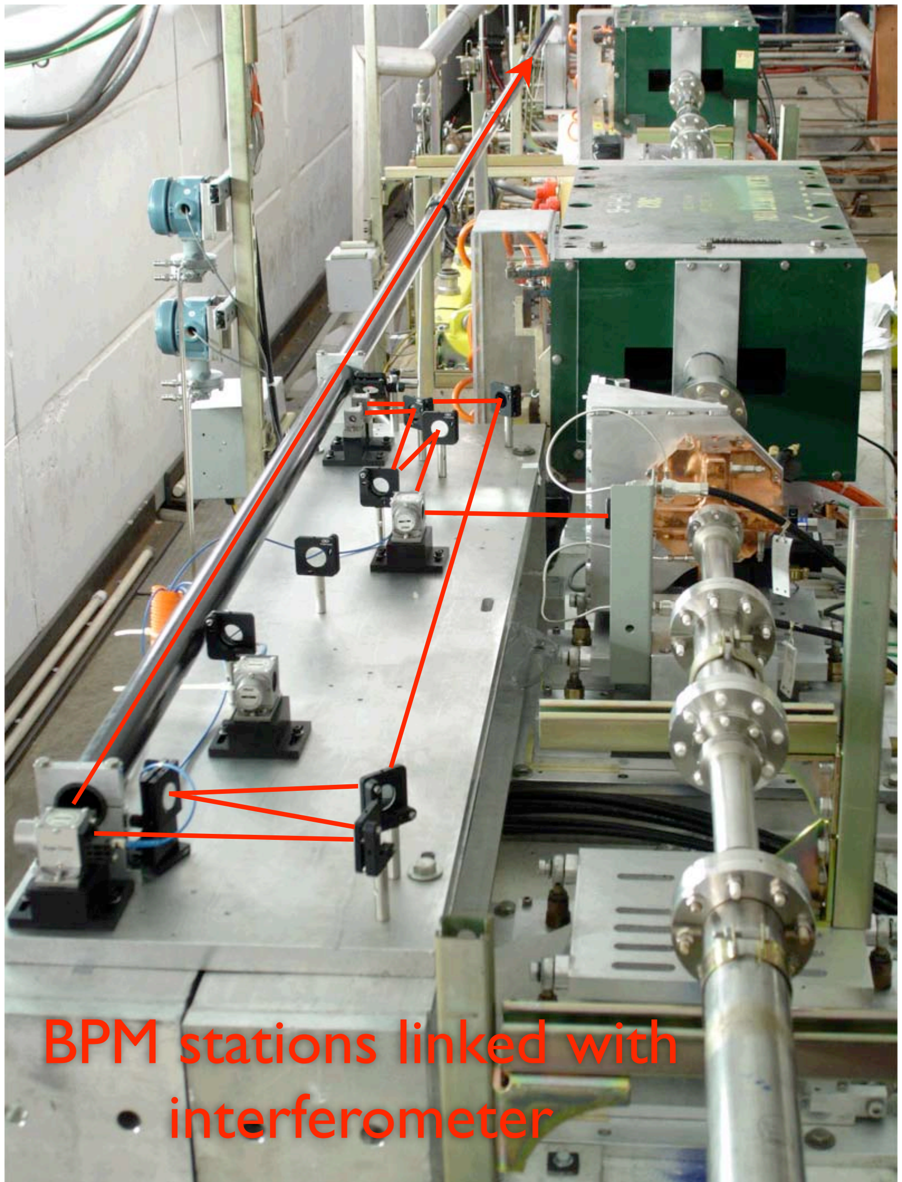
Active R&D Program

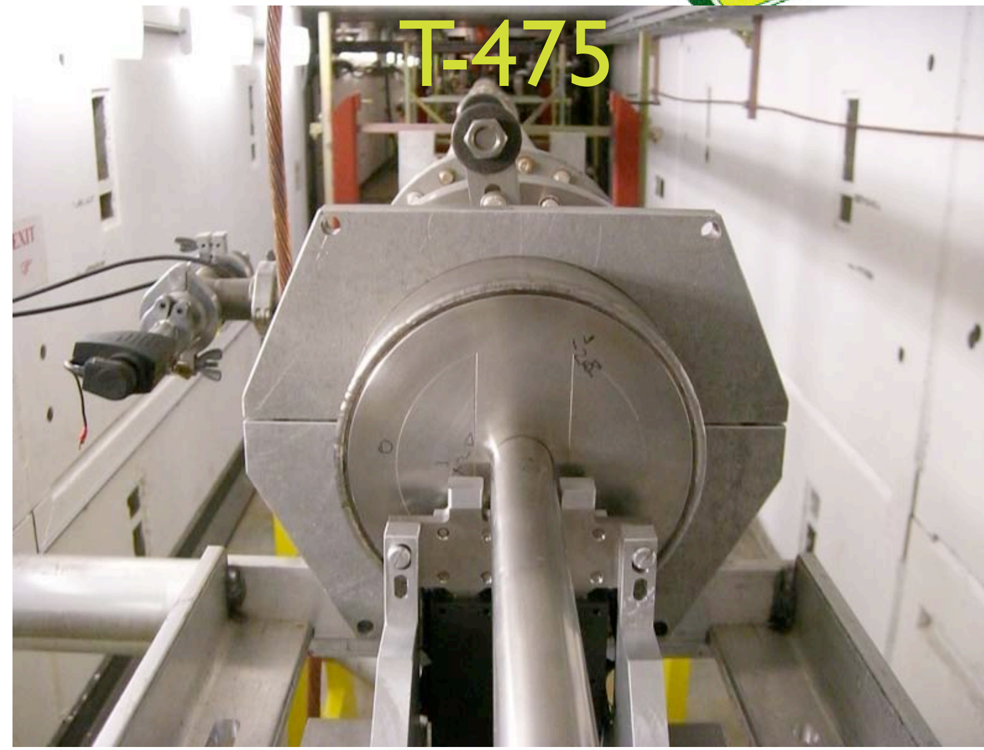
~35 GeV beam parasitic with PEPII operations
2007 Run: 4 dipole chicane + 1 surplus Spear wiggler
Testing RF BPMs, alignment (T-474), Sync. detector (T-475)

Finished latest 3-week run on Wednesday

ESA Energy Hardware

T-474





Quartz Fiber Detector

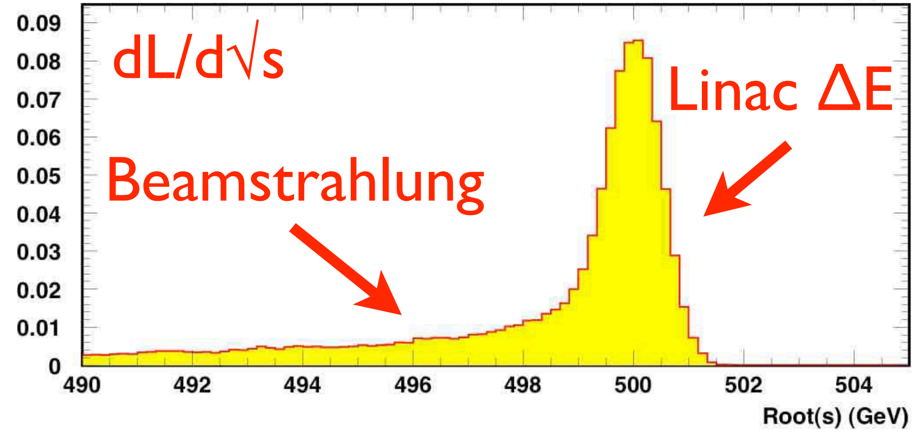
Other Energy Ideas?

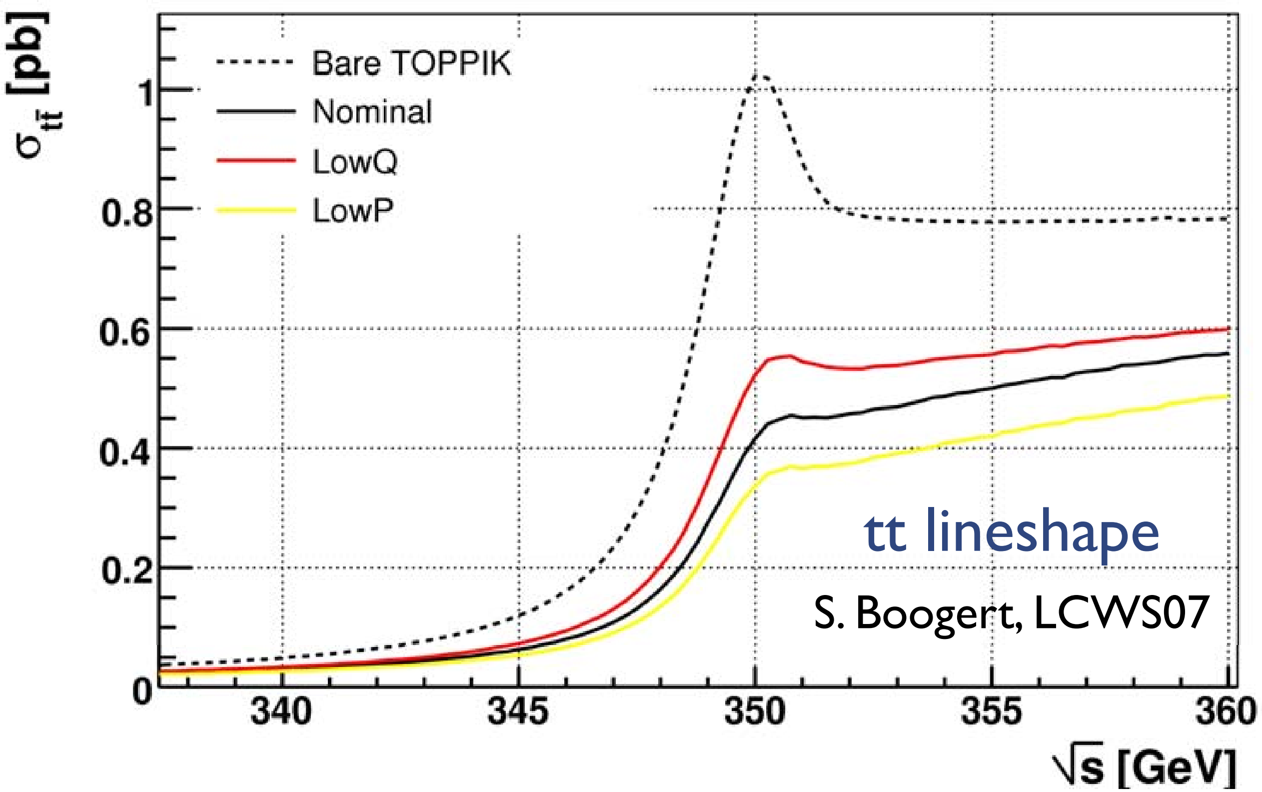
- Designs based on proven concepts in previous machines
- Plenty of intellectual room for other ideas
  - Moller scattering in gas jets
  - Compton scattering
  - Transition radiation
  - Direct dipole synchrotron radiation

Plenty of room for your good idea
GigaZ precision particularly troublesome
Need ideas + simulation and design work

Luminosity Spectrum

- Physics cross-sections are integrated with luminosity spectrum
- Important for lineshape and direct reconstruction

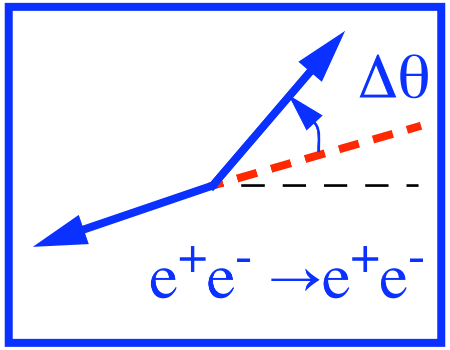




- Similar to ISR corrections
- Can't be predicted by QED
- Highly variable, even pulse to pulse along train

Need to extract average dL/d√s directly from collision data

Bhabha Acolinearity



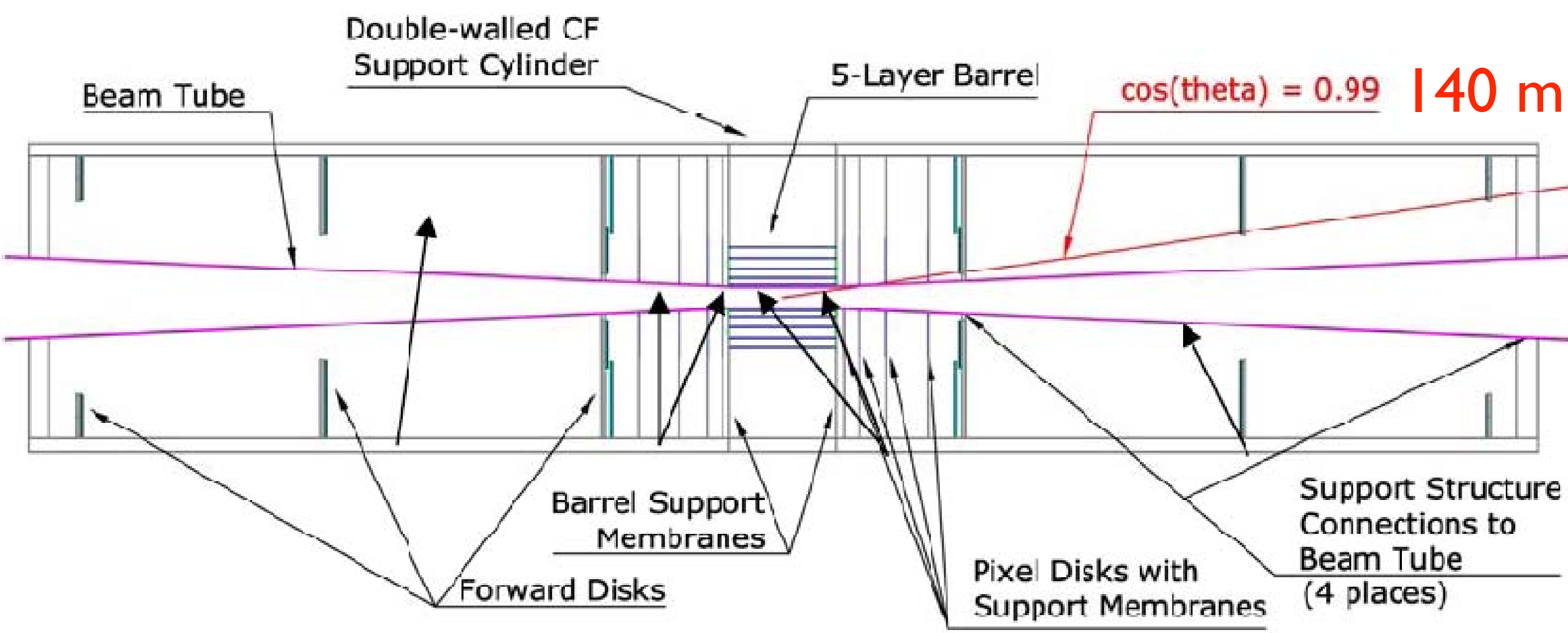
$$\sqrt{s'/s} \approx 1 - \frac{\Delta\theta}{2\sin\theta_0} \qquad \sigma_{\sqrt{s'}} \approx \sigma_{\Delta\theta} E_b / \sin\theta_0$$

Fundamentally measures Lorentz boost

- Forward Bhabhas (rate) but not too forward (resolution) $\sin\theta_0 \sim 150\text{-}200$ mRad

- Need forward tracking with very accurate $\Delta\theta$, $\sin\theta_0$

140 mRad



Beamstrahlung Correlations

$$\langle\sqrt{s}\rangle \neq 2\langle E_{\text{beam}}\rangle$$

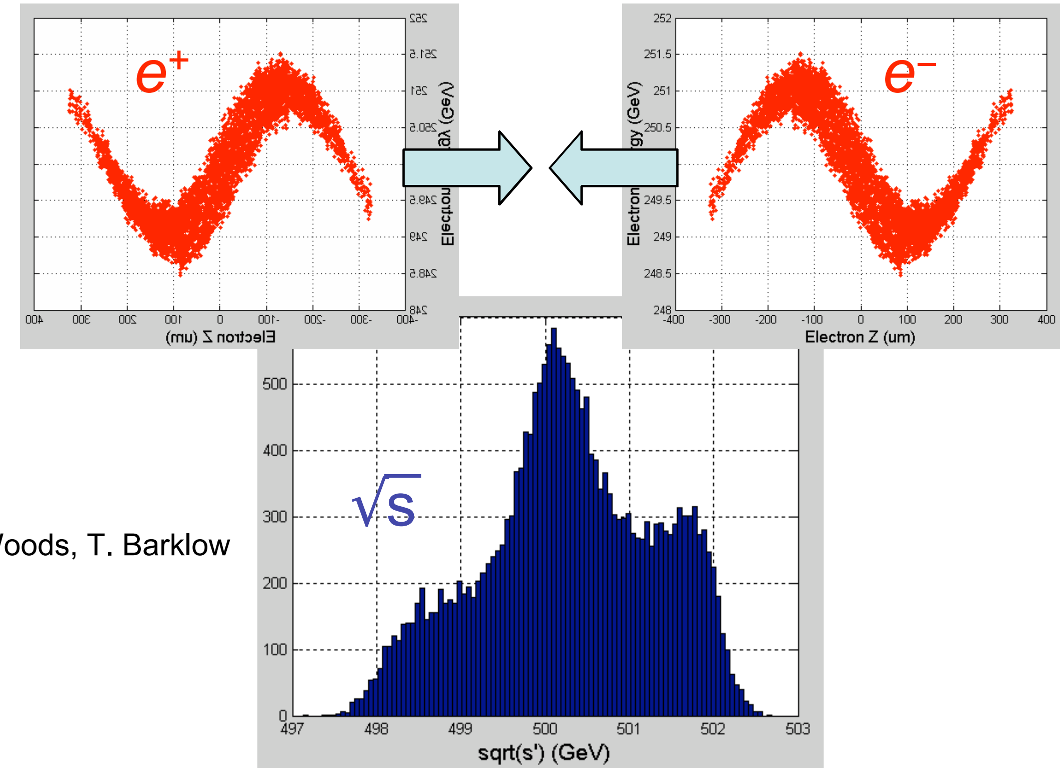
Calibrate with spectrometers
Correct according to lumi spectrum

Bhabha acolinearity assumes uncorrelated emission - not true

Additional corrections needed for (unmeasureable) beam-beam effects!

- Energy - Z correlations
- Head-tail lumi correlations
- Spatial bunch correlations (e.g.: dispersion)

Old NLC Example

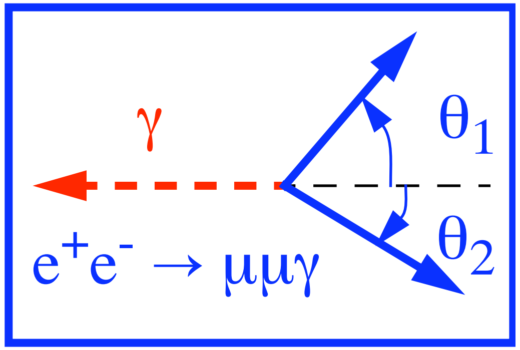


M. Woods, T. Barklow

Uncertainties close to desired accuracy in cold machine (100-200 ppm)

Rely on beam-beam simulation?

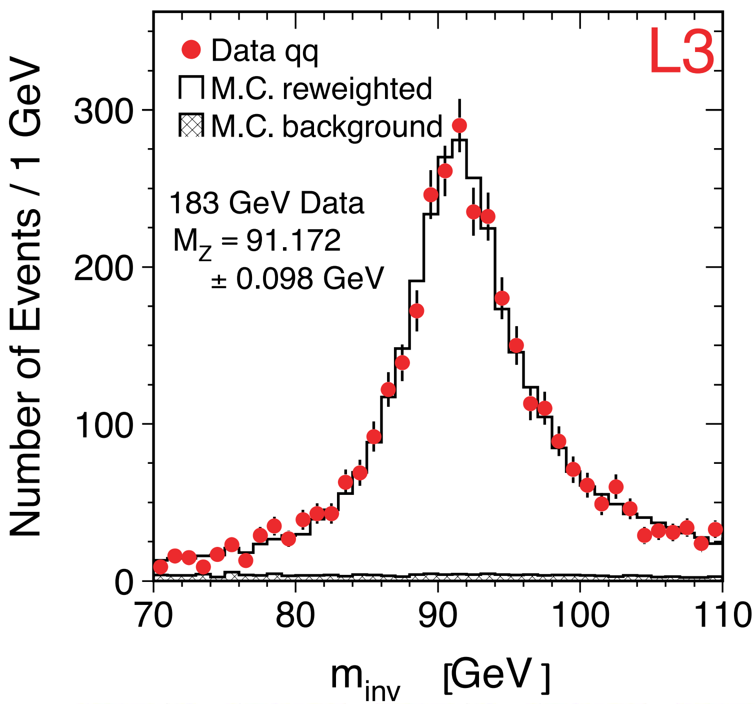
Radiative Returns



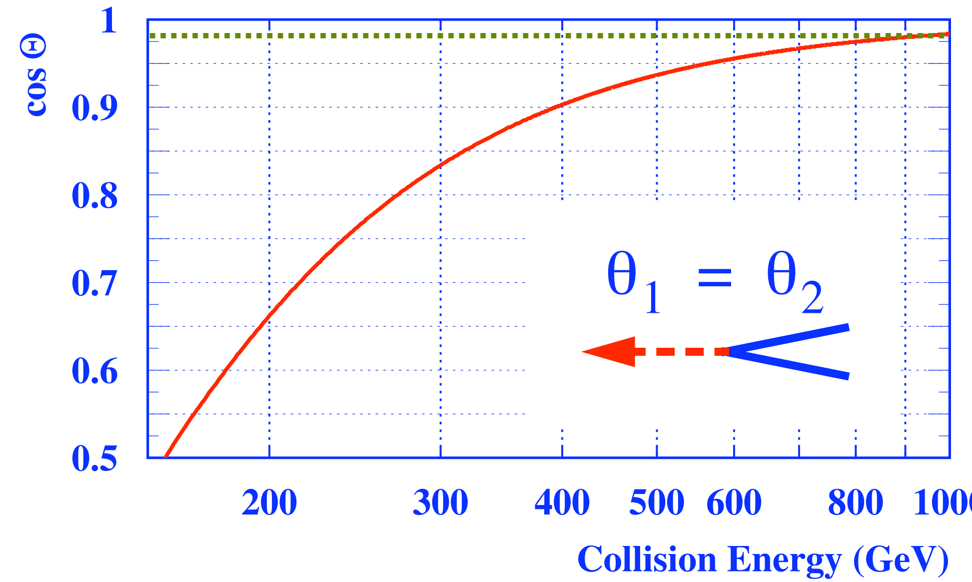
$$\frac{s'}{s} = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1+\theta_2)|}$$

- Observe Z resonance
- Calibrate absolute $\sqrt{s}$ spectrum
- Need absolute θ accuracy at 10^{-4}

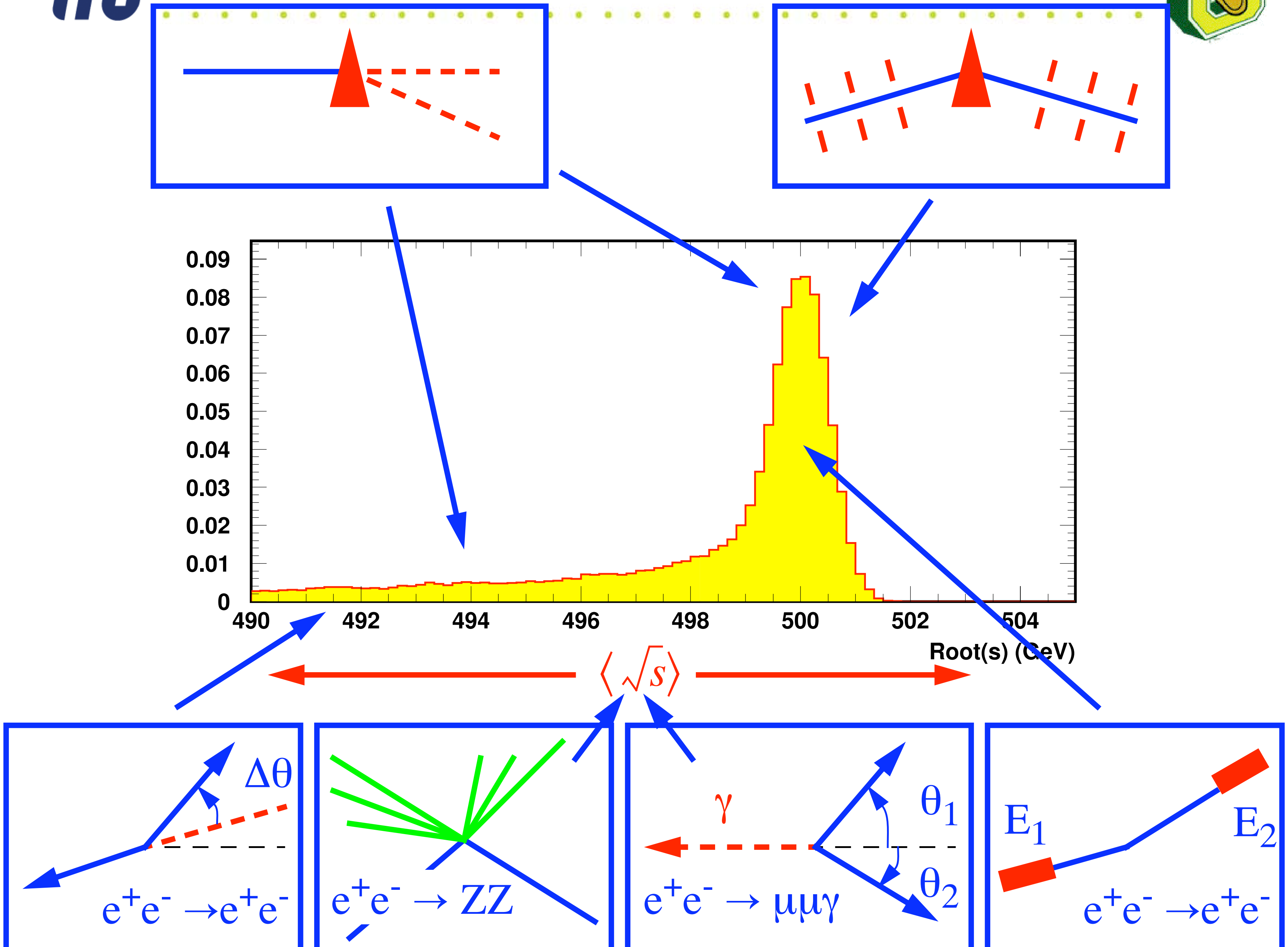
Tried at LEPII



200 mRad

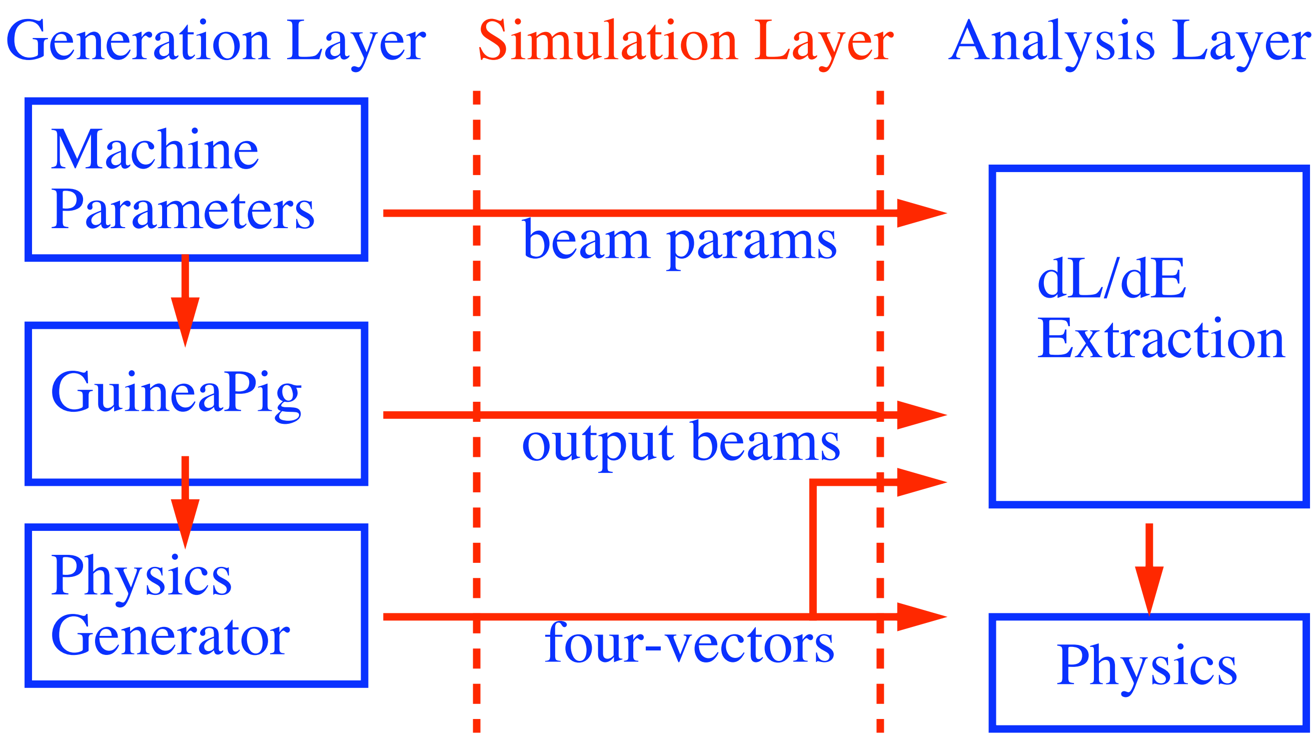


Putting it all together



Close the Loop

It has yet to be demonstrated that all the information is available to extract the luminosity spectrum and collision energy scale to necessary accuracy from beam-based and physics based measurements

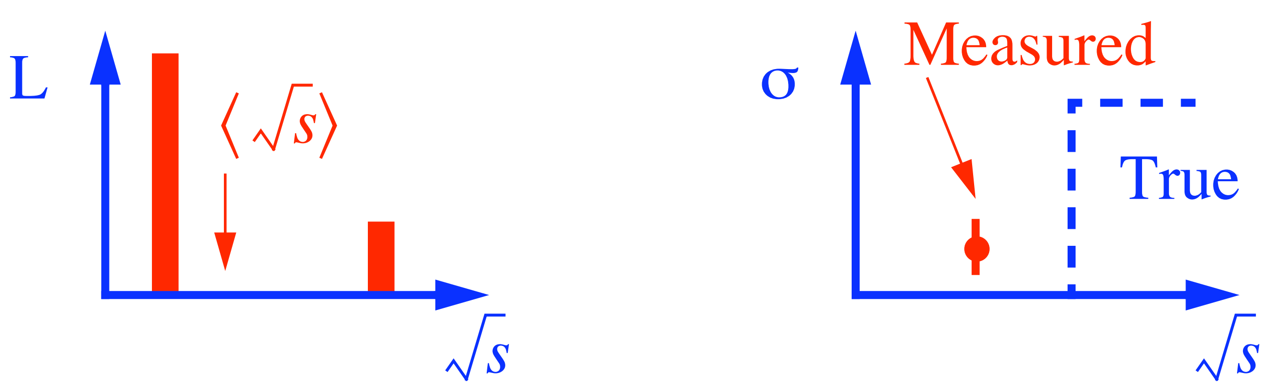


Less than a handful of people working on this worldwide
Needs mix of detector, physics, machine, and *theory*
Fermilab community could play a very big role here!

Just Physics?

Why not just use mean √s, L from physics measurements?

Contrived lineshape example...



$$N = \int \frac{dL}{ds}\sigma(s)ds \text{ not } N = \langle L\rangle \bullet \sigma(\langle s\rangle)$$

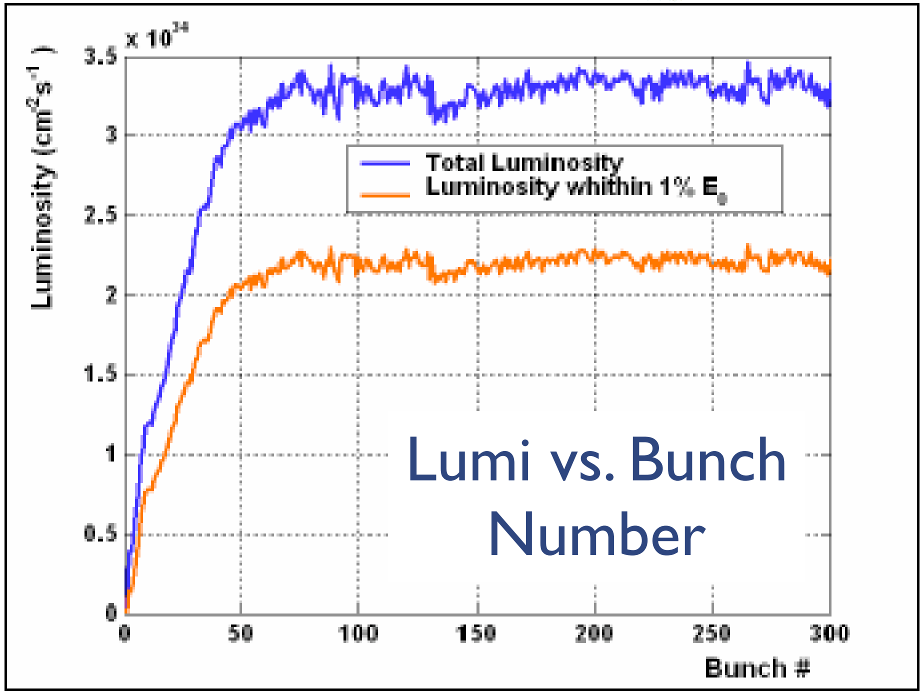
Need dL/d√s spectrum including inter-bunch and intra-bunch variations correlations

May be small effect, but need to prove that!

IP Feedback

- IP feedback to keep beams in collision
- Potential to correlate many nasty effects

Glen White has studied this extensively with misaligned linac simulations into FF simulation into GuineaPig
Extremely slow!



G. White

More investigation of these effects are needed!

Easy transfer of data from machine to detector and back both online and offline will be critical to understanding and correcting many IP instrumentation issues.
This has to work better than any previous accelerator!

Instrumentation Summary

- Polarization design work proceeding well
- Large R&D effort with beam energy spectrometers
- Physics-based extraction of luminosity spectrum and calibration of beam-beam effects needed

The lumi spectrum is the new physics challenge for the ILC. Considerable more effort must be put into this area, particularly in the US involvement!

Precision forward tracking is key to all of this.
This detector must be designed like a precision luminosity monitor with stability, alignment, telemetry all built in.

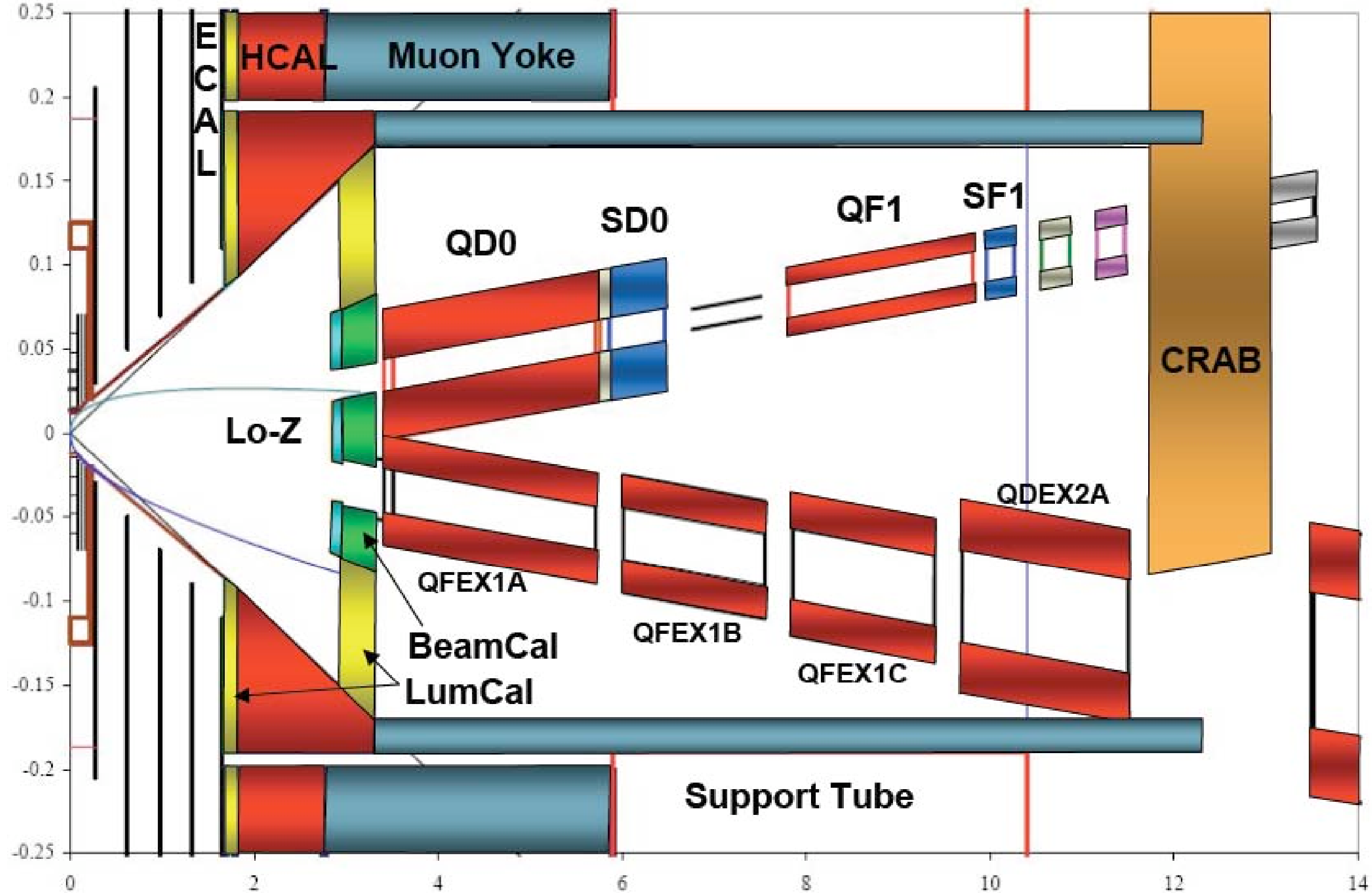
Nobody in the US is working on this*

Interaction Region Engineering

(very brief...)

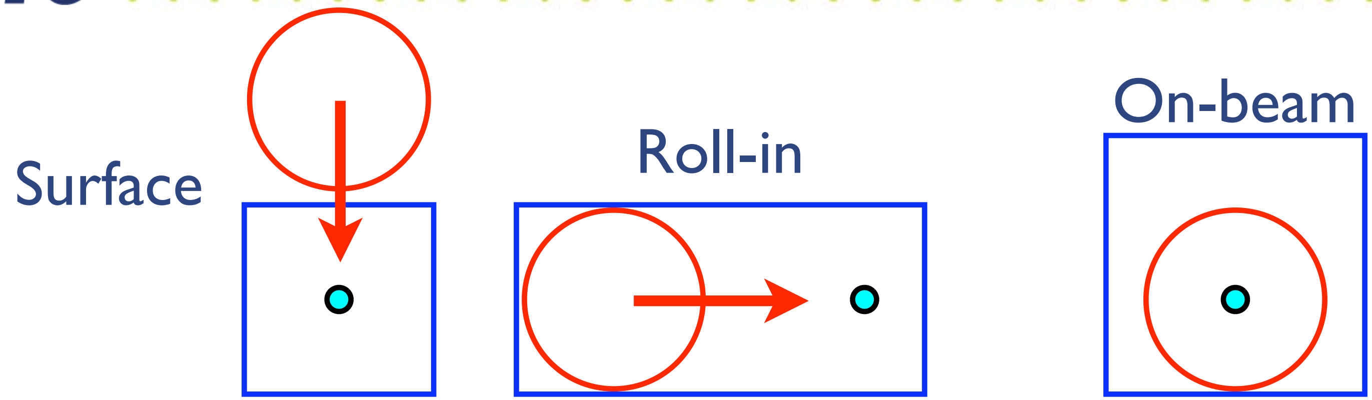
Next phase in IR design

This is a cartoon!



Engineering details starting to be worked out:
Utilities, readout, support, access, etc.
Will occupy large amount of time/effort to EDR

Assembly



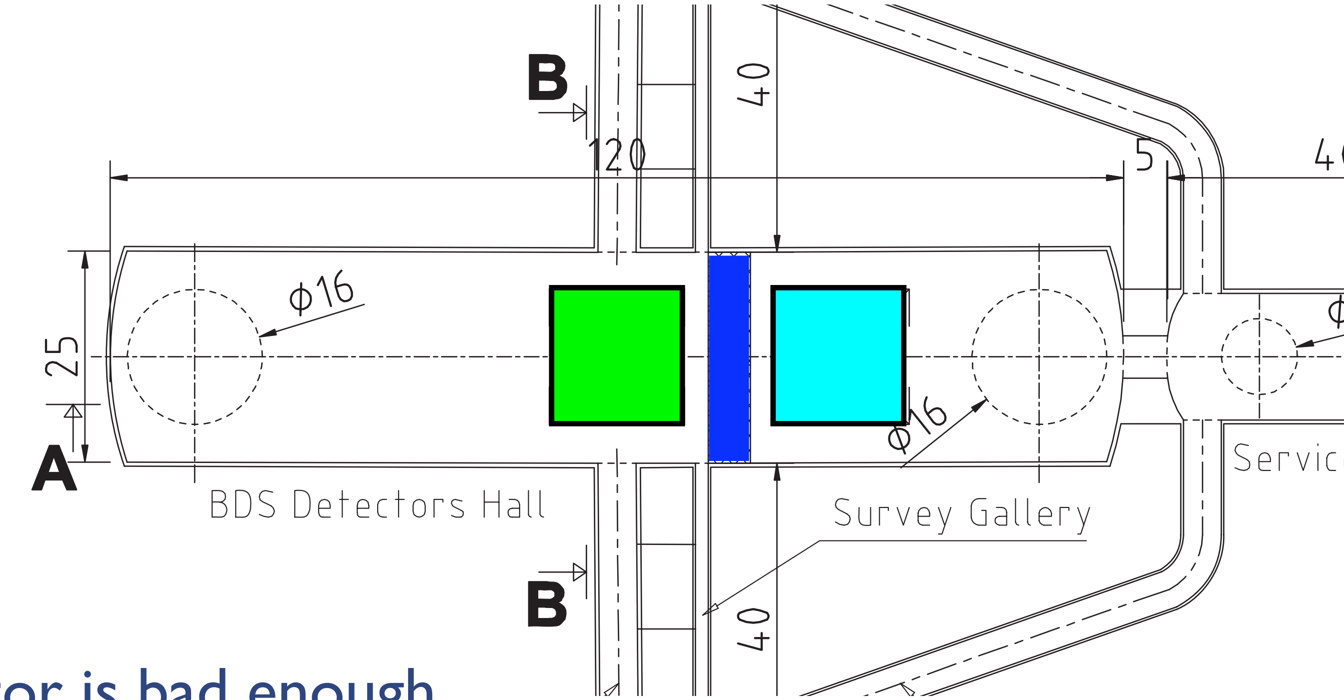
- "Everyone" prefers CMS-style drop-in installation in principle
- Significant (and not fully understood) engineering ramifications

2 kTon max?

Push-Pull

Covered yesterday
by A. Seyri

This is a cartoon!



Moving 15 kTon detector is bad enough
Many other things to worry about:
Cryo, cooling, HV, signal cables, protection systems

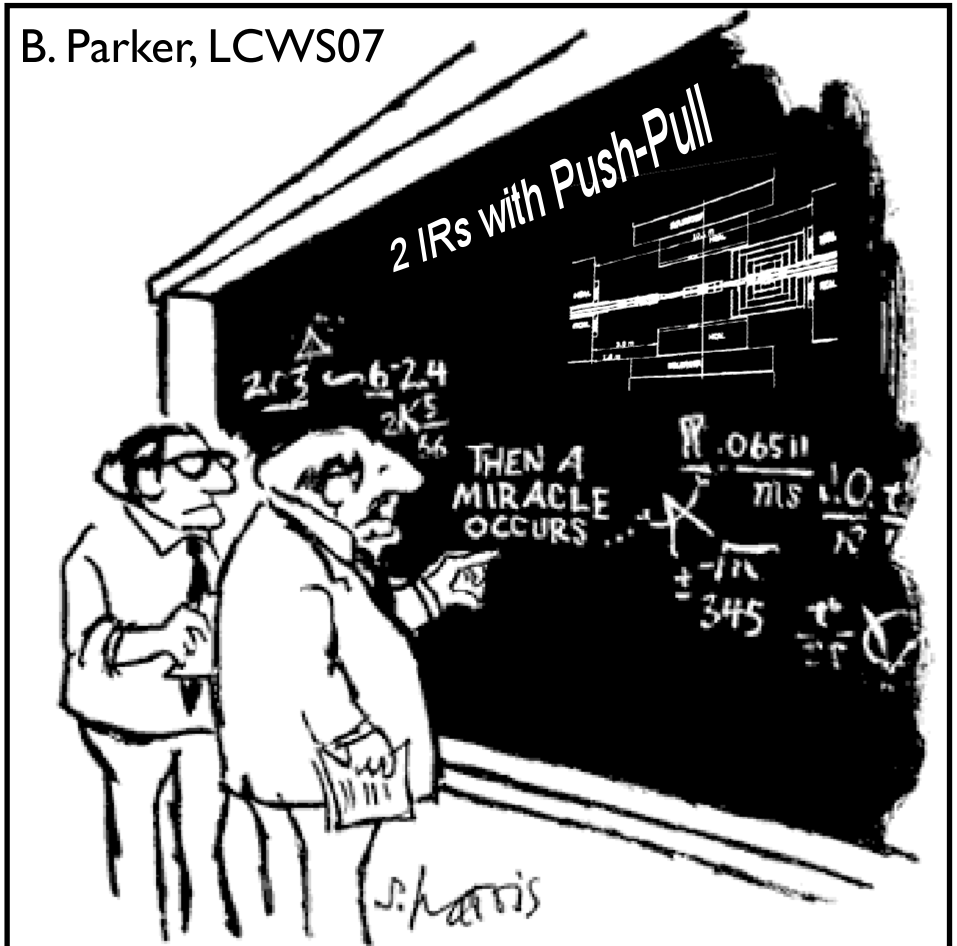
Breakpoint for FF dipoles, support on/off beamline

Detector access on/off beamline
off-beam access during operations, ...

Only makes sense if
changeover is short (few days?)

Push-Pull Summary

B. Parker, LCWS07



"I think you should be more explicit here in step two."

Apologies to Harris - BP.

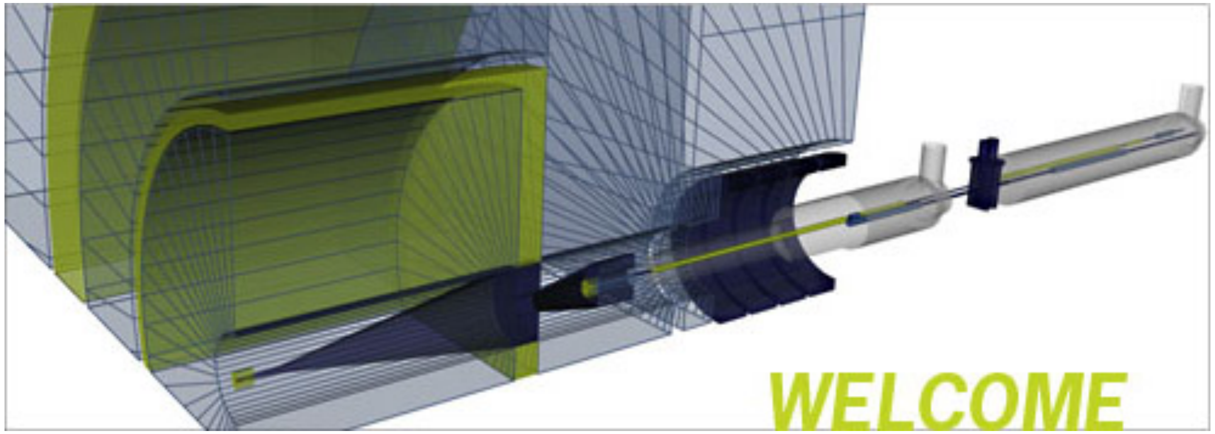
This is a cartoon!

Push-pull represents new scope of engineering challenges...

ILC INTERACTION REGION ENGINEERING DESIGN WORKSHOP

SLAC

- Home
- Goals
- Registration
- Payment Information
- Agenda
- Organizing Committees
- List of Participants
- WorkGroups
- Accommodations
- Travel and Directions
- Visa Information
- Social Events
- Contact



ILC Interaction Region Engineering Design Workshop

September 17-21, 2007
Stanford Linear Accelerator Center
Menlo Park, California

Please join us to review and advance the design of the subsystem of the Interaction Region of ILC, focusing in particular on their integration, engineering design and arrangements for push-pull operation.

RECENT NEWS

- **IPAC has been formed.**
- **WG conveners were nominated.**
- **Working groups have started.**
- **Next meeting: WG-C 7/24**

REGISTRATION

Registration is necessary to participate in the workshop.
Registration fee is $30 and reception fee is $20.

Register

ACCOMMODATIONS

A block of 40 rooms is reserved until July 15, 2007 at the **Stanford Guest House**. Please reserve your room early and mention that you are attending this workshop.

More Information

Sept. 17-21, all interested in engineering issues should attend!
Working groups already meeting now

Summary

Summary

- Beamstrahlung impacts many aspects of MDI
- Background studies ready for Phase II, complete studies with realistic, specific detector geometries
- Forward detector work largely in framework of FCAL

US opportunity, particularly for rad-hard detector development

- Collision energy, lumi spectrum significant new challenge for ILC physics program
- Critical need for precise physics-based cross checks

Precise forward tracking system key to success

- Huge engineering challenges related to "classic" MDI problems: installation, assembly, access, push-pull

Final thoughts

- Most MDI issues have been thought about already
- Existing organizations/structures are making progress
- Progress often limited by resources, warm bodies

New, enthusiastic people very welcome into MDI activities, but people should learn what has already been done and plug into existing efforts.

There is plenty of time for new, good ideas to work itself into the MDI design, but the immediate task is detailed engineering for EDR.
This is where we really need help!

Thanks

- Thanks to the many people working in MDI and Beam Delivery from whom I have lifted results and copied slides

- Particular thanks to Andrei Seyri, Tom Markewicz, and Mike Woods for keeping up the forward progress